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Reduction of Liquid Hydrogen Boiloff: Optimal Reliquefaction System Design and Cost Study

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REDUCTION OF LIQUID HYDROGEN
BOILOFF: OPTIMAL RELIQUEFACTION
SYSTEM DESIGN AND COST STUDY

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PREFACE

This document was prepared by Martin Marietta Corporation under Contract NAS10-9049, Reduction of Liquid Hydrogen Boiloff, Optimal Reliquefaction System Design and Cost Study. The effort was accomplished for the National Aeronautics and Space Administration, John F. Kennedy Space Center. Mr. W. Boggs served as technical monitor for this study.

ACKNOWLEDGMENT

This study resulted from a suggestion by Mr. Frank Howard who has continued to support the efforts throughout. The study Technical Manager for KSC was Mr. Wally Boggs. He was assisted by a management team consisting of Mr. Irby Moore, Mr. Sterling Walker, Mr. Santo DiPasquale, and Mr. Andy Rodrigues of Design Engineering and Mr. Addison Bain of Support Operations. Their contributions were significant to the overall guidance of the study.

The Martin Marietta team consisted of Mr. Charles Class and Dr. Robert McMordie who directed the thermodynamic cycle analyses and life cycle cost studies. The conceptual hardware design and implementation studies were directed by Mr. Dale Spond.

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I. INTRODUCTION

This study performs a preliminary design and economic analysis of candidate hydrogen reliquefaction systems. All candidate systems are of the same general type; differences are size, compressor arrangement, and amount of hydrogen venting. The potential application of the hydrogen reliquefaction will be to reduce the boiloff from the 850,000 gallon storage dewars at LC-39. Conditions considered in performing the study are as follows:

Case 1 Normal daily liquid hydrogen boiloff of 400 gallons per day.

Case 2 Dewar loading of 400,000 gallons (inflow) in waves of tankers of 52,000 gallon total loaded content; loading time nominally 1.5 hours and time between waves (end to beginning) of 6.0 hours.

Case 3 Normal daily boiloff of 400 gallons per day plus storage tank blowdown losses after Space Shuttle filling estimated to be 8500 pounds. Recovery periods of 12, 24, and 48 hours were considered. Assume no helium is present in ullage.

Case 4 Optimal combination of preceding cases as indicated by sizing determinations from Cases 1, 2 and 3.

Normal boiloff is due to heat transfer from the ambient through the insulation and penetrations to the dewar interior. This heat transfer from the ambient is balanced by the energy associated with evaporation of liquid hydrogen. The temperature at the hydrogen liquid/vapor interface is governed by the vent pressure setting on the dewar because saturation conditions exist at this interface. The vent pressure (ullage gas pressure) therefore, determines the thermodynamic state of the hydrogen in the dewar.

The dewars are loaded with liquid hydrogen from tanker trailers. The thermodynamic state of the transferred liquid hydrogen is essentially saturated at 4 to 6 psig. This loading operation introduces liquid that is normally at a higher temperature than the dewar liquid. Also the loading has the effect of pressurizing the dewar. After loading the dewar liquid is at a higher temperature than that consistent with normal boiloff conditions.

Before a launch the dewar is pressurized to approximately 60 psig. This relatively high pressure is used to expell liquid hydrogen from the dewar to the fuel tanks of the launch vehicle. Pressurization is accomplished by withdrawing hydrogen from the dewar, heating the hydrogen by passing it through uninsulated lines exposed to ambient air, and introducing this pressurized and relatively high temperature gas in the dewar ullage. At the end of a launch operation the pressure and average temperature of the hydrogen in the dewar will be considerably higher than the normal boiloff pressure and temperature.

As described in the previous paragraphs, the dewar liquid hydrogen temperature is higher than the normal boiloff temperature after both launch and dewar loadings operations. It is important to vent the dewar to normal boiloff conditions in a relatively short time after these operations so it will be ready to support a launch.

A large amount of hydrogen is lost in venting the dewar to normal boiloff conditions. The actual amount is a function of the dewar pressure and the amount of liquid in the dewar before venting (blowdown). The 8500 pounds previously quoted in Case 3 is a result of dewar blowdown after a launch.

Hydrogen losses due to blowdown after dewar loadings were not defined in the contract Statement of Work. This loss has been estimated (refer to calculations in Appendix A) to be approximately 8300 lbm. This value is based on assuming the dewar is at normal boiloff conditions and contains 20% liquid by volume. Four hundred thousand gallons of liquid hydrogen are loaded in the dewar from the tankers at a saturation pressure of 21 psia. These conditions cause the dewar pressure to be 24.7 psia after loading. Finally, venting the tank pressure down to normal boiloff conditions, results in the 8300 lbm loss.

Section IX contains the results of an extension to the basic study. A specific case system utilizing two compressors and twenty-five per cent cycle venting was selected for developing a conceptual design. All major components were sized and detailed. The study includes a detail weight analysis, a structural analysis of the dewar, a plan for penetrating the dewar, a thermal analysis of the penetration area, a conceptual design of the control system and a failure modes and effects analysis.

This study shows that 1.9 to 2.9 million pounds of hydrogen can be saved over the 15 year shuttle program for each hydrogen storage dewar, depending upon the number of shuttle launches per year. The capital investment for the hydrogen reliquefaction system is estimated in 1978 dollars at $607,000. This results in an economic payback of capital investment in 2 to 3 years.

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A. BACKGROUND

A closed-loop reliquefaction cycle using liquid nitrogen boiloff was chosen as the type of system to investigate because it was identified as optimal based on the contract, *Reduction of Liquid Hydrogen Boiloff Reliquefaction Cycle Analysis*, NAS10-8937, June 1976. A diagram of this system is shown in Figure I-1. In the diagram note that nitrogen vacuum pumping is provided to reduce the nitrogen boiling temperature to a minimum. Also, the condenser is located in the ullage of the dewar. It is recommended in this study that vacuum pumping not be provided and that the condenser be located in the cold box, exterior to the dewar. The reason for deleting the vacuum pumping is that the only practical location for the vacuum pump is on the ground. Because the LN_2heat exchanger must be on top of the dewar, a relatively long line is required between the vacuum pump and the heat exchanger. Vacuum pumping over this length (over 100 ft) is not practical. The reason for placing the condenser on the dewar exterior is to minimize the dewar/reliquefaction system interface. By placing the condenser outside the dewar, this important goal will be met because only a single gas-line penetration and a single return liquid-line penetration are required.

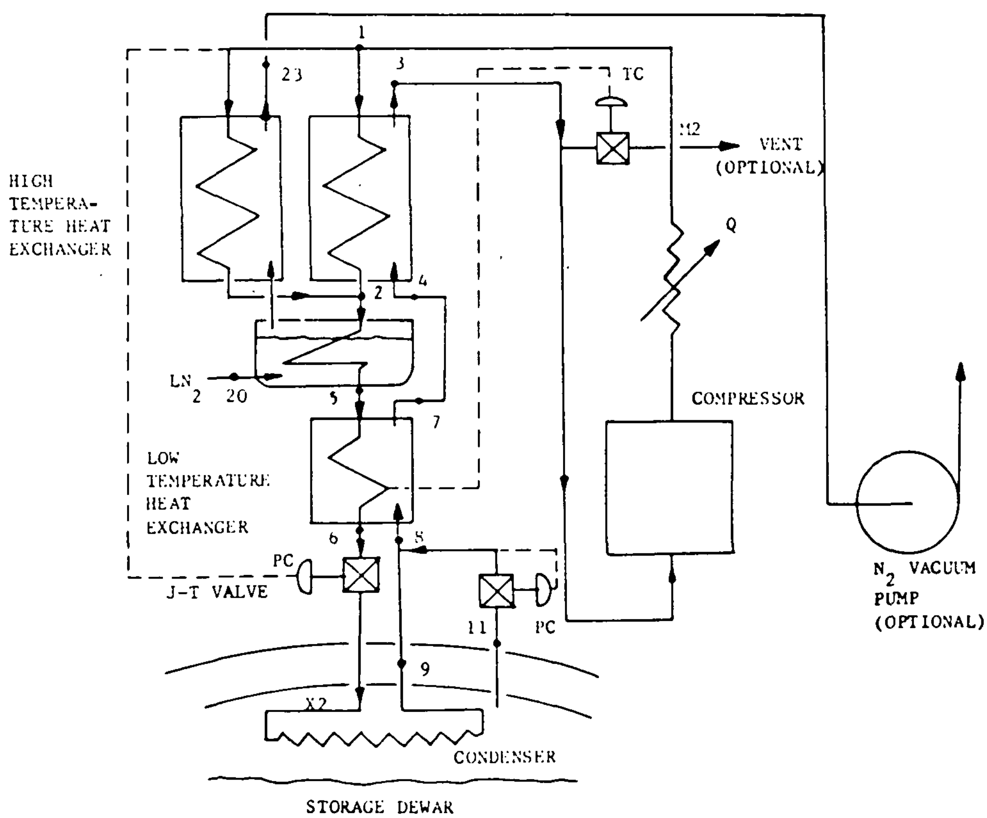

Figure I-1
Closed Loop-LN_2 Precooled Reliquefaction Cycle (Defined in Previous Study)

B. APPROACH

The first step in this study was to analytically model the reliquefaction cycle using the Martin Marietta Interactive Thermal Analysis System (MITAS), our generalized thermal analyzer program. The model includes detailed heat transfer simulation of the heat exchangers, thermodynamic simulation of the compressor, and the pressure drop predictions throughout the system. Primary outputs of the system simulation program are the yield, electrical power requirements, cooling-water requirements, and LN_2 requirements for a given set of conditions and given system size. These data are input to a life-cycle cost program along with capital equipment costs, operating costs, maintenance costs, and cost escalation estimates. The life-cycle cost program, which was developed for this study, predicts the overall saving for a system of given size.

II. SUMMARY

Our proposed system flow diagram is shown on Figure II-1. The vacuum-insulated cold box is located at the top of the dewar. The compressor is on the ground adjacent to the dewar. The only interface between the reliquefaction system and the dewar are the lines connecting the condenser to the dewar ullage.

A. VARIATIONS OF SYSTEMS INVESTIGATED

Several variations of the basic closed-cycle design were investigated. A baseline system was sized first that liquefied the 400 gallons of normal daily boiloff only. Numerous system-level computer runs were made to establish the baseline. The criteria used in this exercise were to force the pressure drop between the condenser and the compressor inlet to approximately 1 psi and to maximize the yield.

After having sized the baseline system, it was imagined that two compressors would be installed in parallel. One of these compressors would carry the normal boiloff load; the second compressor would be brought on-line for Space Shuttle launch and dewar loading operations only. In all systems described to this point, the heat exchangers, lines, Joule-Thomson valve, and condenser sizes are identical. The final variation was to size a system that could carry the total dewar loading boiloff. This system, which requires four compressors, obviously, is oversized for the normal boiloff conditions.

For the three basic system sizes investigated, the effect of venting dewar ullage gas through the low-temperature heat exchanger and high-temperature hydrogen heat exchanger was studied. This use of ullage gas in the cycle, which would otherwise be completely lost during post-Shuttle launch and dewar loading, significantly reduces LN_2 requirements and increases the yield. To distinguish this type of venting from venting directly to the atmosphere, we will use the term "cycle venting" for vent gases that flow through the reliquefaction system's heat exchangers. In this study, 5, 10, and 25% cycle venting were investigated. The percentage values are relative to the flow through the compressors.

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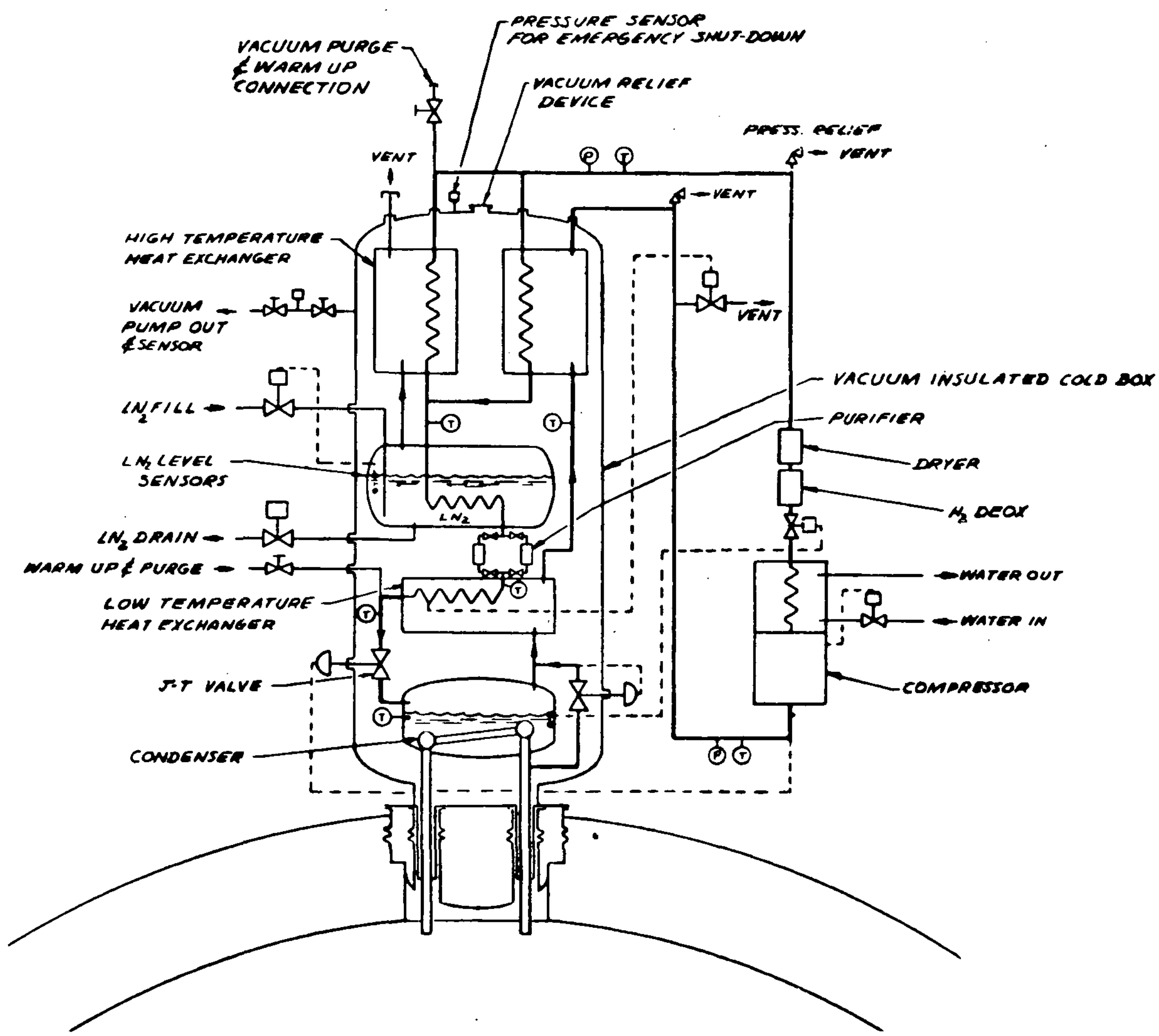

Figure II-1 Proposed System Flow Diagram

B. POTENTIAL COST SAVINGS

A summary of the potential savings is given in Table II-1. Note that all systems considered show a significant saving over the life of the system. It is our opinion that system 1 using two compressors and 25% cycle venting is the optimum (preferred) because it represents large savings and yet minimizes the cold-box size and weight that must be supported by the dewar. Analysis shows the cold box weight for system 1 is 5380 lbm and for system 2 is 20,100 lbm.

Figure II-2 shows the sensitivity of savings to various parameters relative to a baseline design. Figure II-3 illustrates hydrogen savings sensitivity.

C. DEWAR MODIFICATION AND COLD BOX INSTALLATION

Minor structural additions are required to the outer shell of the dewar to spread the loads imposed by the cold box. The cold box can be attached to the dewar at the existing manhole. The penetration can be designed so that there is virtually no heat loss.

D. SAFETY AND CONTROL SYSTEM

The incorporation of a LH_2 reliquefaction system should in no way jeopardize the operational or structural integrity of the dewar. The control system uses standard pressure and liquid level sensing equipment which automatically shuts down the reliquefaction system in the event of any equipment malfunction or loss of power. In the event of shut down, the reliquefaction system becomes passive and the dewar continues to function normally, as if the reliquefaction system did not exist.

Table II-1 Life-Cycle Cost Savings Summary

Sys	No. of Compressors	% Cycle Venting	Baseline [1]		Launch Hours Parameter				No. of Launches Parameter				Operational Life Parameter				Capital Investment Parameter [3]		Hydrogen Cost Escalation Parameter [3]	
					24 hr		12 hr		25 Launches		15 Launches		20 years		10 years		+20%	-20%	10%	6%
			$ Saved[2]	lbm H_2 Saved	$ Saved	lbm H_2 Saved	$ Saved	lbm H_2 Saved	$ Saved	lbm H_2 Saved	$ Saved	lbm H_2 Saved	$ Saved	lbm H_2 Saved	$ Saved	lbm H_2 Saved	$ Saved	$ Saved	$ Saved	$ Saved
1	1	0	0.978	1.214	0.978	1.214	0.978	1.214	0.978	1.214	0.978	1.214	1.141	1.618	0.629	0.809	0.898	1.059	3.353	2.150
1	1	5	1.277	1.364	1.248	1.350	1.234	1.343	1.351	1.402	1.202	1.327	1.554	1.819	0.819	0.910	1.196	1.357	3.946	2.594
1	1	10	1.519	1.491	1.467	1.465	1.442	1.452	1.654	1.561	1.348	1.422	1.886	1.988	0.878	0.994	1.438	1.599	4.437	2.959
1	1	25	2.116	1.818	2.007	1.760	1.952	1.731	2.400	1.969	1.832	1.667	2.695	2.424	1.372	1.212	2.036	2.196	5.673	3.871
1	2	0	1.786	1.934	1.704	1.869	1.662	1.836	1.992	2.099	1.580	1.770	2.083	2.579	1.191	1.290	1.686	1.934	5.571	3.654
1	2	5	2.425	2.260	2.283	2.163	2.211	2.115	2.791	2.506	2.060	2.014	2.968	3.013	1.606	1.507	2.326	2.260	6.848	4.608
1	2	10	2.937	2.526	2.745	2.404	2.649	2.343	3.431	2.838	2.444	2.213	3.673	3.368	1.939	1.684	2.838	3.037	7.880	5.367
1	2	25	4.207	3.211	3.894	3.024	3.737	2.930	5.018	3.695	3.396	2.727	5.399	4.282	2.774	2.141	4.107	4.307	10.49	7.307
2	4	0	3.988	3.654	3.666	3.416	3.505	3.297	4.793	4.249	3.183	3.059	4.798	4.872	2.695	2.436	3.849	4.127	11.14	7.516
2	4	5	4.211	3.765	3.778	3.472	3.561	3.325	5.072	4.388	3.350	3.143	5.109	5.021	2.839	2.510	4.073	4.350	11.58	7.847
2	4	10	4.399	3.864	3.871	3.521	3.608	3.350	5.307	4.511	3.491	3.217	5.367	5.152	2.961	2.576	4.260	4.538	11.96	8.130
2	4	25	4.878	4.127	4.111	3.653	3.727	3.416	5.905	4.840	3.850	3.414	6.014	5.502	3.277	2.751	4.739	5.016	12.95	8.862

[1] Baseline case is defined as: 48 hr associated with launch, 20 launches/yr, 15-yr system life, no hydrogen cost escalation.

[2] All savings in millions.

[3] lbm of hydrogen saved is same as baseline.

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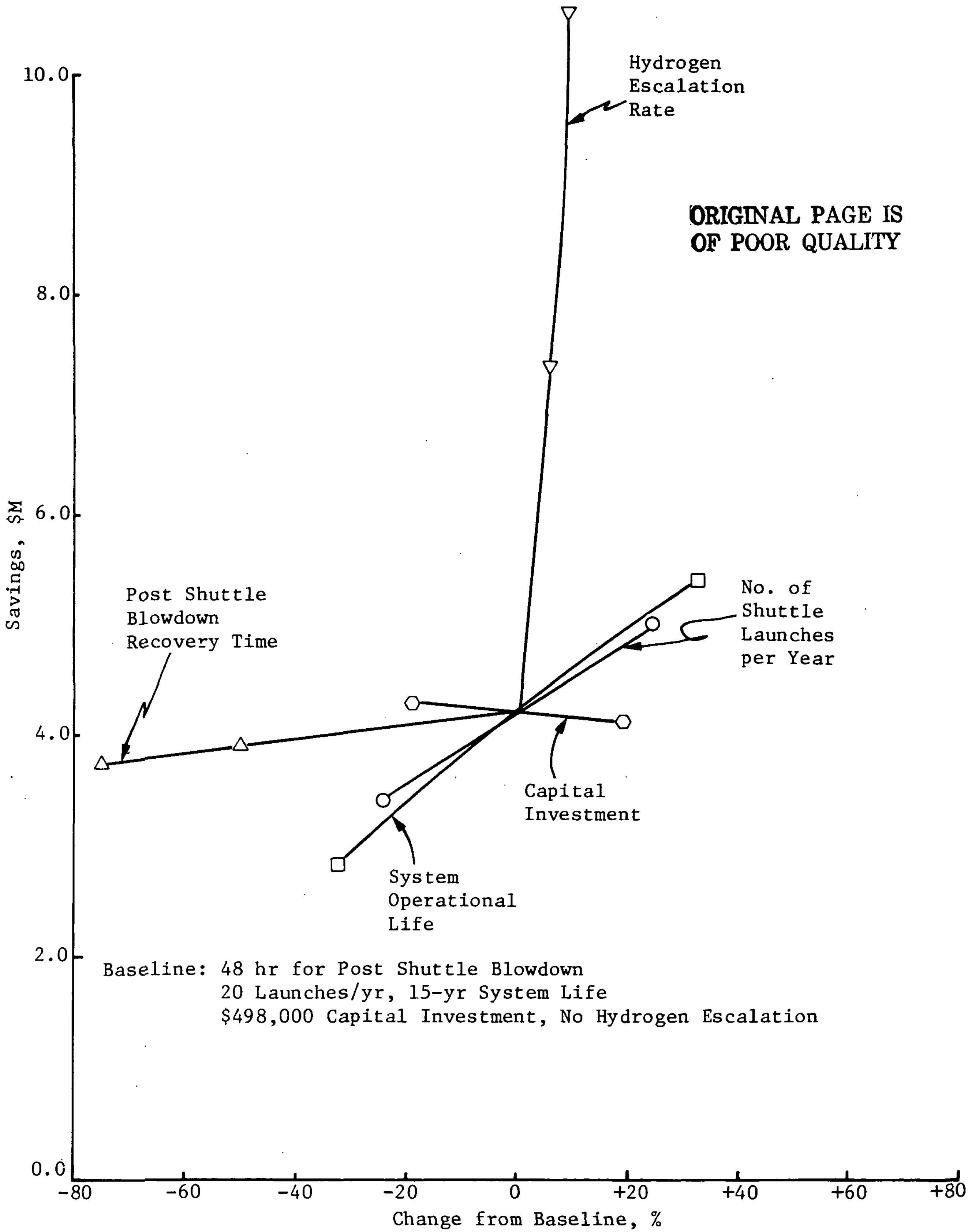


Figure II-2 Influence of Study Parameters on Costs Savings for System 2, 25% Venting

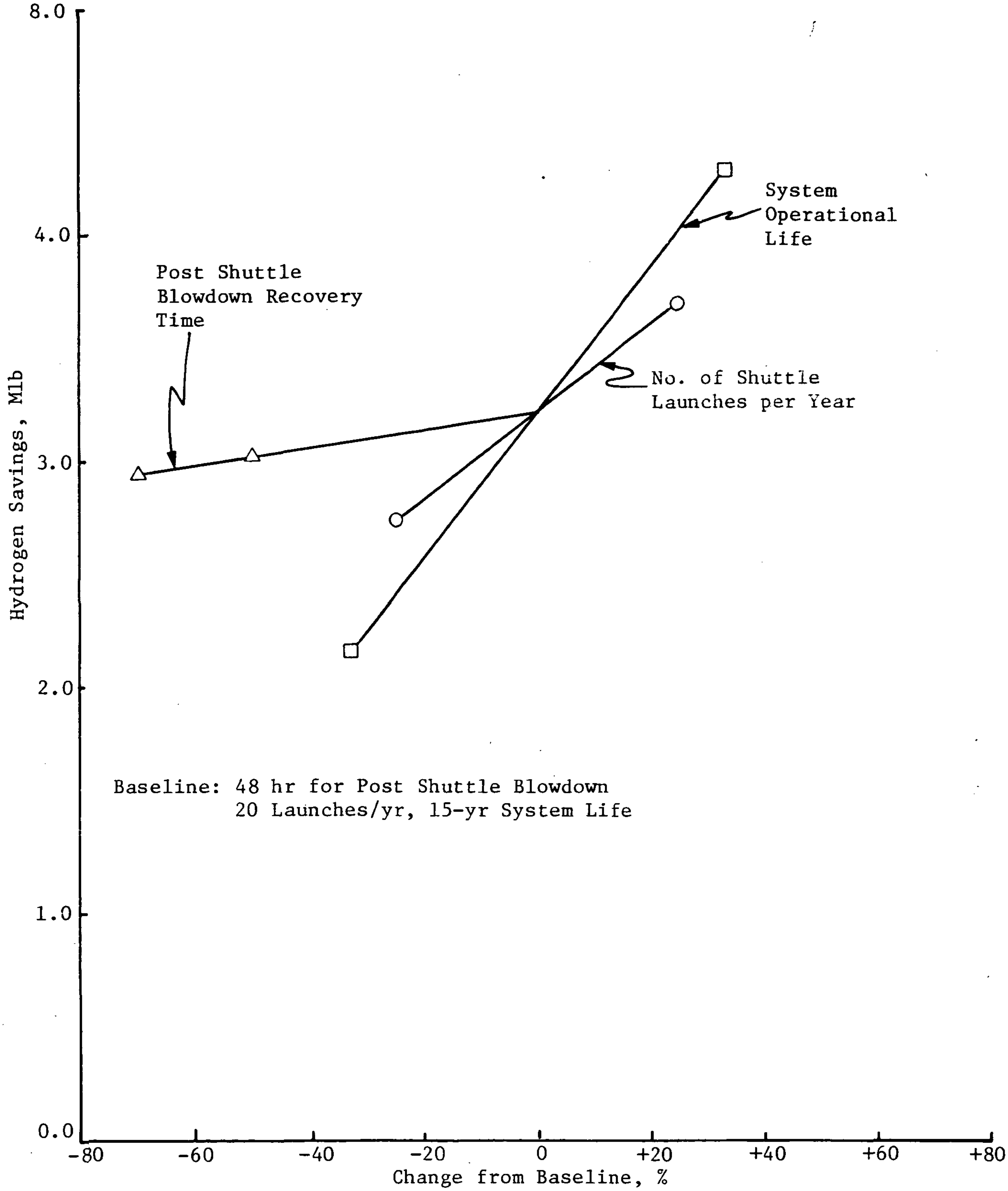


Figure II-3 Influence of Study Parameters on Hydrogen Savings for System 2, 25% Venting

III. CYCLE ANALYSIS

The approach used in performing this study was to analytically model the reliquefaction cycle using our generalized thermal analyzer program, Martin Marietta Interactive Thermal Analysis System (MITAS). Elements of this analytical model are shown in Figure III-1. The system thermal network is given in Figure III-2. Subroutines were used to establish the compressor performance, pressure drops throughout the system, and "real gas" hydrogen properties. Fluid flow and heat transfer are coupled through program logic. A listing of MITAS inputs are given in Appendix C.

A. HEAT EXCHANGER MODELING

Giauque-Hampson-type exchangers were used in the system simulation model for the low-temperature and high-temperature exchangers in the cold box. The low-temperature exchanger was modeled using 113 nodes and 175 conductors. The conductors, which represent gas convection and enthalpy transfer, are both pressure and temperature dependent, This detailed modeling is required for the low-temperature heat exchanger because it is the most critical in the system. Also, this approach automatically avoids "pitch" temperature problems. The entire low-temperature exchanger network is defined and generated automatically by five user constants. These constants are as follows:

1) Outside package diameter

2) Inside package diameter

3) Number of tubes

4) Tube diameters

5) Package length

The remaining heat exchangers are modeled using the Number of Transfer Units (NTU) approach. This is a common technique used in heat transfer analysis.

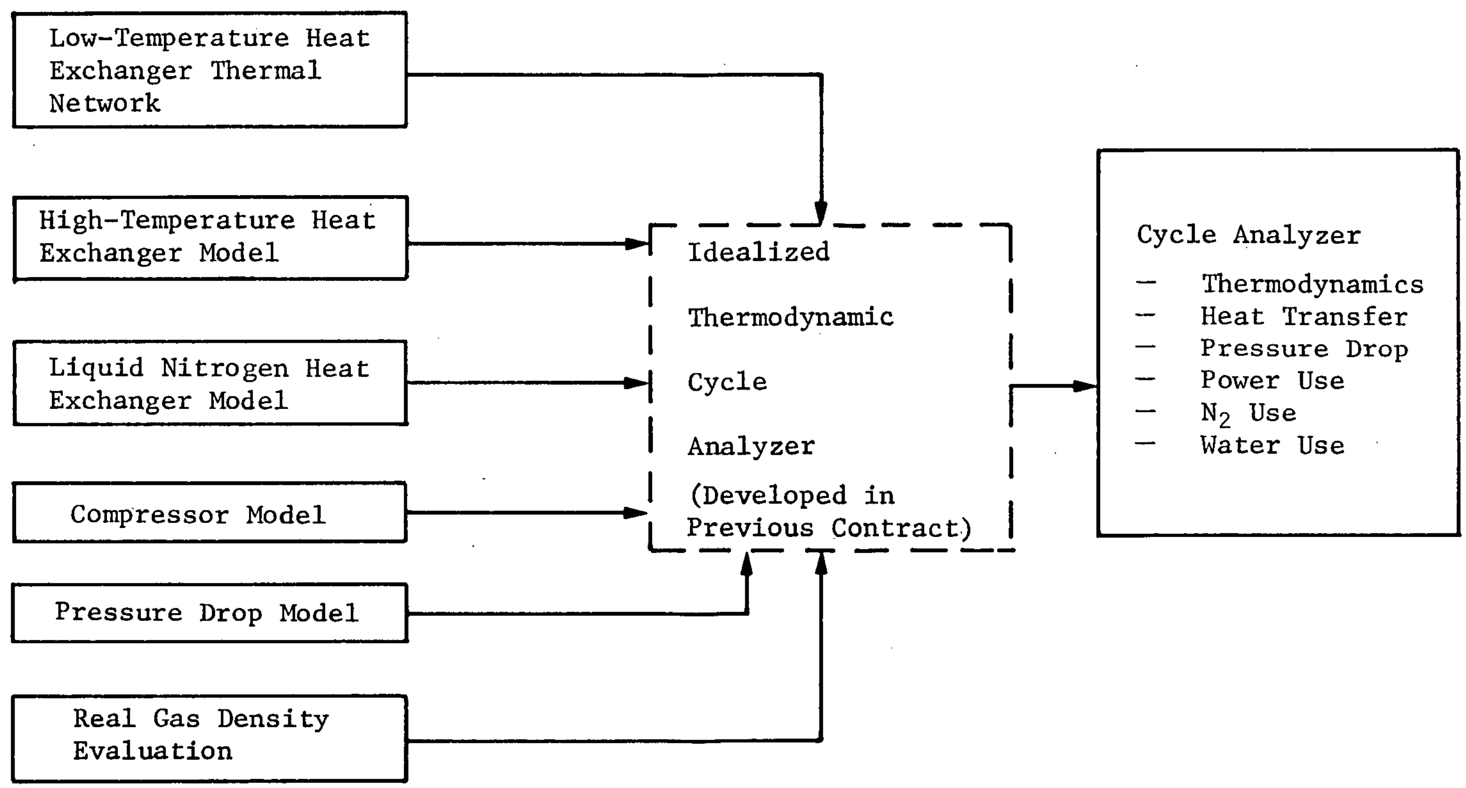


Figure III-1 Cycle Analyzer Model Development

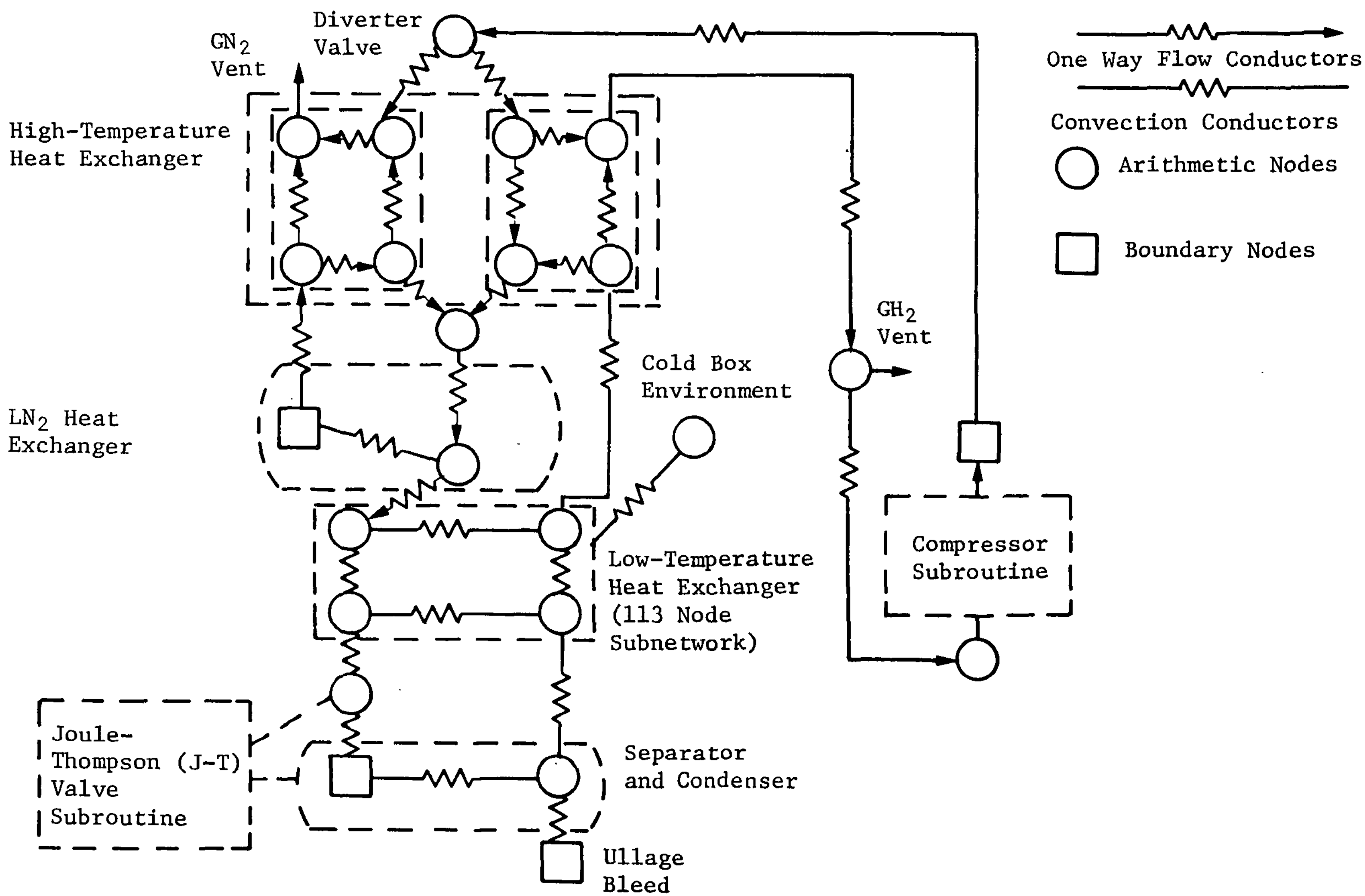


Figure III-2 System Thermal Network

B. COMPRESSOR MODELING

Analytical modeling of the compressor was based on the following assumptions:

1) Compression is adiabatic

2) Mechanical efficiency = 95%

3) Cp/Cv = 1.401

4) Water-cooled intercoolers and an aftercooler used

5) Hydrogen outlet temperatures at coolers 10°F above inlet cooling water temperature

6) 3% pressure loss for each compressor stage

Given the hydrogen inlet pressure, inlet temperature, and volume displacement the compressor subroutine calculates the hydrogen outlet pressure, outlet temperature, power requirement, and cooling water requirement. These assumptions were established after discussion with a compressor vendor.

C. CONDENSER MODELING

The condenser modeling is based on work by K. D. Timmerhaus, reference 1. This paper describes the condensing coefficient for hydrogen based on experimental work.

D. PRESSURE DROP

Pressure drop equations are included in the reliquefaction computer simulation model so system performance estimates will be as realistic as possible. Two classes of pressure drops are evaluated; one is internal pipe flow and the other is across tube bundles. For pipe flow, the program checks for laminar or turbulent conditions and computes the friction factor consistent with whichever type of flow is present. Also, equivalent pipe length estimates are made depending on elbows, valves, tees, and check valves present in the lines. Detailed exchanger geometry is accounted for when estimating the pressure drop across the heat exchanger tube bundles. For both pipe and tube bundle pressure drop calculations, the properties of the hydrogen are varied and this variation is coupled to the heat transfer analysis.

1. Pipe Flow

The mass rate of flow at the compressor inlet is known because the compressor size (SCFM) is specified, the inlet pressure is fixed, and the inlet temperature is continuously computed and updated. With this quantity defined, the cycle vent flow specified, and the system geometry known, the mass rates of flow are defined at all points in the system. The fluid flow equations, therefore, are written in terms of the mass rates of flow as follows:

[1] $V = 0.0003537 \frac{\dot{m}}{\rho d^2}$

Where $\dot{m}$ = mass rate of flow, lb_m/hr

ρ = density, lb_m/ft^3

d = pipe inside diameter, ft

V = fluid velocity, ft/sec

[2] $Re = 3600\ \rho v d/\mu$

ρ = density, lb_m/ft^3

V = velocity, ft/sec

d = inside diameter, ft

μ = viscosity, $lb_m/ft\text{-}hr$

RE = Reynolds number

If $Re \leq 2300$

$f = 64/Re$

$RE > 2300$

$f = 0.0056 + 0.5/Re^{0.32}$

f = friction factor

The pressure drop is given by:

[3] $$\Delta P = 7.336 \times 10^{-6} \frac{f L_T \rho V^2}{d}, \text{ atmospheres}$$

Where $L_T = L_L + (2.6N_e + 26\ N_v + 5.56\ N_T + 6.2N_{cv})\ d$

L_T = total effective line length, ft

L_L = line length, ft

N_e = number of elbows

N_v = number of valves

N_T = number of tees

N_{cv} = number of check valves

d = line diameter, ft

ρ = density, lb_m/ft^3

V = velocity, ft/sec/

The coefficients attached to the number of elbows, valves, etc. were taken from Crane Company data.

2. Flow Across Tube Bundles

The following equations are taken from *Cryogenic Systems*, Randall Barron, McGraw-Hill, 1966. It is assumed that the tubes are in line with the transverse and longitudinal pitch equal.

[4] $$A_{min} = \frac{\pi}{2} \left(D_o + D_i\right) \left[\tfrac{1}{2} (D_o - D_i) - d(N_t)\right]$$

Where D_o = exchanger annulus outside diameter, ft

D_i = exchanger annulus inside diameter, ft

d = tube outside diameter, ft

N_t = number of tubes in radial direction

A_{min} = minimum flow area, ft^2

[5] $G_{max} = \dot{m}/A_{min}$, $lb_m/hr\text{-}ft^2$

Where $\dot{m}$ = mass rate of flow, lb_m/hr

[6] $Re = d\ G_{max}/\mu$

Where μ = viscosity, $lb_m/ft\text{-}hr$

[7] $$f' = \left\{ 0.176 + 0.32 \left(P_{L/d}\right) \left[\left(P_{T/d}\right) -1\right]^{-n} \right\} Re^{-0.15}$$

Where P_L = longatudinal pitch, ft

P_T = transverse pitch, ft

d = tube outside diameter, ft

Re = Reynolds number

$n = 0.43 + 1.13\ d/P_L$

f' = friction factor

The pressure drop is given by

[8] $$\Delta P = 5.66 \times 10^{-13} \frac{f'N\ G^2_{max}}{\rho}, \text{ atmospheres}$$

Where N = number of in line tubes in flow direction;

ρ = density, lb_m/ft^3

E. PROPERTY EVALUATION

1. Density of H_2

The density of hydrogen is required for the reliquefaction system program for both heat transfer and pressure drop calculations. Because pressures and temperatures vary over wide ranges, the ideal gas relation is not appropriate. Alternatives for specifying density as a function of temperature and pressure were to input an NBS table,* use NBS equations, or develop an equation. It was decided to take the latter approach because the manpower required to input the tables was excessive and both manpower requirements and computer time would be excessive if a set of extremely complex NBS equations were employed. It should be noted that the technique that has been developed is not as accurate as the NBS equations. At low temperatures (40°R) and high pressures (1500 psia) the error in density is approximately 5%; this represents a worst-case error. Generally the error is ±2% or less, which is well within acceptable limits. It should also be noted that the work reported here is based on para-hydrogen data. However, NBS TN 641 states that PVT relations do not change from para to ortho to normal hydrogen, therefore this work relates to hydrogen in general.

The first step in defining the density is to write the van der Waals equation of state for hydrogen.

[9] $\rho^3 - 4.721\rho^2 + \rho\,(0.06472\ P + 0.11049T)$

$-0.30555\ P = 0$ p in atms. and T in °R

Let $F = \rho^3 - 4.721\rho^2 + \rho\,(0.06472\ P + 0.11049T)$

$-0.30555\ P$

$$\frac{\partial F}{\partial \rho} = 3\rho^2 - 2 \times 4.721\rho + (0.06472\ P + 0.11049T)$$

[10] $$(\rho)_{N+1} = (\rho)_N - \left[F \Big/ \frac{\partial F}{\partial \rho} \right]_N$$

For the initial guess at ρ let $(\rho)_o = 2.762\ \frac{P}{T}$ (ideal gas equation)

---

*"Provisional Thermodynamic Functions for Para-Hydrogen", NBS Tech. Note 130, Dec. 1961.

Repeatedly apply equation [10] until

$$\left| (\rho)_{N+1} - (\rho)_N \right| < \beta$$

where β is the convergence criteria.

Finally, compute the density by applying the following equations:

$$[11] \quad \rho_c = \frac{\rho}{1 - \varepsilon}$$

$$\text{where } \varepsilon = \left\{ 0.2e^{-(T/105)^{5.96}} + \frac{2000}{(T-126)^2 + 2000} (0.00138P - 0.06944) \right\} \left(1 - e^{-(P/20)^4}\right)$$

An example of various estimates of density versus experimental data from NBS tables is as follows:

P, psia	T, ^{o}R	ρ(NBS), lbm/ft^3	ρ(vdw),* lbm/ft^3	ρ_c, lbm/ft^3	ρ(ideal gas), lbm/ft^3	$\frac{\rho(NBS) - \rho_c}{\rho(NBS)}$ x 100, percent
1000	40	4.7506	3.834	4.820	4.697	1.46
1000	60	4.0850	3.2883	4.114	3.132	0.71
1000	80	3.1918	2.6754	3.247	2.349	1.73
1000	100	2.2894	2.0882	2.354	1.879	2.85
1000	126	1.6035	1.5500	1.606	1.491	0.16
1000	150	1.2703	1.2490	1.2703	1.253	0.0
1000	200	0.90851	0.9015	0.907	0.939	0.17

*van der Waals

2. Enthalpy and Specific Heat

A table of enthalpy and specific heat versus pressure and temperature was included in the system model. It was necessary to include these data in tabular form so that accurate values of enthalpy could be developed for the low-temperature heat exchanger calculations. It was found during the course of the study that if this was not done temperature equilibrium would be indicated by the computer solution without satisfying the first law of thermodynamics. This was due to the real gas effects on hydrogen properties at low temperatures and high pressures.

F. SYSTEM PERFORMANCE

Table III-1 lists the results of the cycle analyses. Actually many additional computer runs were made, iterating on individual component sizes to establish optimum configurations.

Table III-1 Hydrogen Reliquefaction Thermal Model Summary

	System Description	Operational Mode	Compressor Flow LBM/Hr	Compressor Flow SCFM	Increase in Flow Due to Cycle Venting: Flow, %	Increase in Flow Due to Cycle Venting: LBM/Hr	Hydrogen Liquefied Gal/Day	Hydrogen Liquefied LBM/Hr	Nitrogen Boiloff Gal/Day	Nitrogen Boiloff LBM/Hr	Power kW	Water Gal/Hr	Dewar Press. Atm	Dewar Temp K	Condensor Press. Atm	Condensor Temp K	J-T Valve Press. Atm	J-T Valve Temp K	Liq H_2 Yield %
System 1*	1 Compressor, No Venting	Normal Boiloff	34.2	106	0	0	400.8	9.86	65.83	18.54	42.49	69.97	1.30	21.19	1.07	20.63	85.73	41.55	28.86
	1 Compressor, 5% Venting**	Loading	34.2	106	5	1.71	486.6	11.98	48.19	13.58	42.29	69.97	1.31	21.19	1.07	20.64	85.77	39.83	35.06
		Launch					480.0	11.84	48.12	13.57			2.72	24.18	1.07	20.64	85.77	39.97	34.66
	1 Compressor, 10% Venting	Loading	34.2	106	10	3.42	559.6	13.77	37.90	10.68	42.29	69.97	1.31	21.19	1.08	20.64	85.79	38.15	40.32
		Launch					548.8	13.51	37.96	10.69			2.72	24.18	1.08	20.64	85.79	38.40	39.54
	1 Compressor, 25% Venting	Loading	34.2	106	25	8.54	764.2	18.37	24.43	6.88	42.29	69.97	1.31	21.19	1.08	20.66	85.81	33.08	53.76
		Launch					727.4	17.90	24.86	7.00			2.72	24.18	1.08	20.66	85.81	33.88	52.41
	2 Compressors, No Venting	Normal Boiloff	68.3	212	0	0	773.5	19.04	147.3	41.49	84.57	139.4	1.31	21.19	1.13	20.82	79.83	41.88	27.87
	2 Compressors, 5% Venting	Loading	68.3	212	5	3.42	960.6	23.64	111.3	31.35	84.57	139.4	1.31	21.19	1.13	20.83	79.96	40.17	34.61
		Launch					947.7	23.83	111.3	31.35			2.72	24.18	1.13	20.83	79.96	40.29	34.15
	2 Compressors 10% Venting	Loading	68.3	212	10	6.83	1113.0	27.39	87.06	24.52	84.57	139.4	1.31	21.19	1.14	20.85	80.04	38.47	40.10
		Launch					1091.0	26.85	87.21	24.57			2.72	24.18	1.14	20.85	80.04	38.73	39.31
	2 Compressors, 25% Venting	Loading	68.3	212	25	17.08	1506.0	37.07	50.84	14.31	84.57	139.4	1.31	21.19	1.16	20.90	80.17	33.49	54.27
		Launch					1461.0	35.96	51.42	14.48			2.72	24.18	1.16	20.90	80.17	34.23	52.64
System 2***	4 Compressors, No Venting	Normal Boiloff	145	450	0	0	1748.0	43.02	263.3	74.17	179.5	295.8	1.32	21.28	1.08	20.66	86.91	41.34	29.66
	4 Compressors, 5% Venting	Launch	145	450	5	7.25	2063.0	50.78	188.9	53.20	179.5	295.8	2.72	24.18	1.08	20.67	86.91	39.84	35.02
	4 Compressors, 10% Venting	Launch	145	450	10	14.50	2342.0	57.64	149.7	42.16	179.5	295.8	2.72	24.18	1.09	20.68	86.92	38.33	39.75
	4 Compressors, 25% Venting	Launch	145	450	25	36.25	3087.0	75.98	101.8	28.68	179.5	295.8	2.72	24.18	1.09	20.71	86.93	33.87	52.40

*System 1 is sized to liquefy the normal daily boiloff of 400 gallons with no cycle venting.
**Percent of cycle venting is the ullage gas flow through the low pressure side of the system, relative to compressor flow.
***System 2 is sized to liquefy the normal boiloff and the dewar loading conditions with no cycle venting.

G. ANALYSIS OF SPECIAL SYSTEMS

During the course of study it was recognized that compressing the hydrogen at liquid nitrogen temperature (77K), rather than ambient temperature, would significantly reduce the electrical power requirement. An analysis of this low-compression temperature approach showed that this was indeed the case; the power changed from approximately 4 (kW-hr/lbm liquefied) for ambient compression to approximately 0.7 (kW-hr/lbm liquefied) for low-temperature compression. However the LN_2 requirement increased from 2 (lbm LN_2/lbm liquefied) for high temperature compression to 30 (lbm LN_2/lbm liquefied) for low-temperature compression. The cost of the additional LN_2 more than makes up for the saving in power and, therefore, this low-temperature compression approach is not competitive.

IV. SYSTEM DESIGN CONSIDERATIONS

A. KSC INTERFACES

Major interfaces between the hydrogen reliquefaction system and the dewar are the dewar penetration and attachment of the cold box on top of the dewar. Further, the reliquefaction system requires electrical power, cooling water for compressor intercoolers and an aftercooler, and a liquid nitrogen supply. These interfaces must be specified in detail. We have investigated this area on a preliminary basis and no problem is apparent.

B. SAFETY

Experience with the many hydrogen liquefiers and refrigerators used throughout the country demonstrates that they can be designed safely. The following sections present items of importance that need particular attention when designing a safe hydrogen reliquefier.

1. Air Leakage

Introduction of air into a hydrogen reliquefaction system is serious. Fractions of a million parts of air leakage into the system during the reliquefier operation will freeze in the low-temperature heat exchanger and in the J-T valve. Solid air can accumulate after a period of time causing freezeup of the process or, more seriously, detonation. It is believed that the fracturing of an air or oxygen solid crystal releases sufficient energy to explode. Both freezeup of hydrogen liquefiers and explosions have occurred in prior operating systems. Great care must be taken to keep air out of the system and purifiers must be used to remove any air from the system.

To keep air out of the system, the following actions are required:

1) Low-pressure piping should be kept above atmospheric pressure. Therefore, if there is any leakage, hydrogen will leak out and air will not leak inward. The compressor inlet pressure will be the lowest pressure point and must be controlled.

2) During initial charging of the reliquefier with hydrogen, all air should be removed by evacuation and purge procedures.

3) A deoxo unit must be used to remove residual air in the system after charging with hydrogen and must continue to be used if any potential exists for introduction of air.

4) Gas holders should not be used for long-duration operations because air will diffuse into the hydrogen within the holder, even if the hydrogen pressure is higher than the ambient air pressure. (Reliquefiers have been designed without use of low-pressure gas holders.)

5) The problem of air entering hydrogen reliquefiers by being absorbed in the oil used in the compressors has been essentially solved by preprocessing the oil through vacuum pumps to remove absorbed air and then storing the oil under a blanket of helium. It is our opinion that nonlubricated compressors are a practical option for the reliquefaction system under study. If they are used, there should be no problem of air entering the hydrogen stream at the compressors.

6) A momentum chamber should be used in the high-pressure system after the low-temperature heat exchanger and before the J-T valve. This is an enlarged volume that slows down the gas before entering the J-T valve. Its use is to keep any solids formed in the heat exchanger out of the J-T valve.

2. Hydrogen Leakage

Normally hydrogen leakage will quickly diffuse in the air and escape. Areas where hydrogen could accumulate and become hazardour are common in a reliquefier. These areas include compressor crank cases, compressor stuffing boxes, reliquefier cold boxes, roof spaces, instrumentation boxes, and control panels. The following should be accomplished to prevent hydrogen leakage problems:

1) Weld and braze all piping wherever possible. Use mechanical fittings sparingly.

2) Do not run hydrogen piping through closed compartments.

3) If closed areas are required that contain hydrogen, purge areas with nitrogen, helium, or evacuate areas.

4) Provide adequate ventilation in all areas where hydrogen is used. Locate equipment in open air whenever possible.

5) Use alarm system to sense hydrogen in the air at controlled locations.

6) Ensure that electrical equipment is of the appropriate class and explosion proof.

7) Check operation of the system. Make visual checks and review operating records.

3. <u>High Pressures</u>

Use of high pressure hydrogen in a process flow system requires overpressure protection. In addition, monitoring capabilities are required to determine quickly the status of operations.

Effect the following practices:

1) Use ASME pressure code criteria in design of plumbing subsystems.

2) Use overpressure relief valves in all lines to prevent rupture. Vent valves to a vent stack that is preferably weather capped and maintains a small nitrogen purge. The purge is for those lines passing through enclosed areas.

4. <u>Operating Procedures and Standards</u>

The operation of the reliquefier must be carefully controlled through use of detailed procedures. The system is to be designed for automatic shutdown in case of failure. Items to consider include:

1) Trained operators and personnel;

2) Detailed procedures;

3) Graphic control panels for rapid statusing;

4) Automatic controls with normal overrides;

5) Recording equipment to measure temperatures and pressures in the system;

6) Provisions to warm and purge critical areas of the system such as the low-temperature heat exchanger and J-T valve.

C. FAILURE MODES

Primary failure modes are shown in Table IV-1. The system should be designed so each is continuously monitored. If any of the measured values exceed safe limits the system automatically shuts down. The monitored quantity is obvious on all the listed items with the possible exception of items 2 and 3 in the table. For these items, pressure sensors should be installed at the low temperature heat exchanger and the J-T valve to indicate if freeze-up or plugging problems occur.

Table IV-1. Primary Failure Modes

Item	Failure Mode
1. Compressor	Low oil pressure Low water flow Low water pressure
2. Low-Temperature Heat Exchanger	Freeze up or plugging
3. J-T Valve	Freeze up or plugging
4. Cold Box	Loss of Vacuum
5. Complete System	Leakage
6. Facility	Power failure

D. CONTAMINATION INSTRUMENTATION

It is important to know if the hydrogen is contaminated and the extent of contamination. With a closed system, however, it is not apparent if any or just how much sensing instrumentation is needed. Also, many of the sensors required to monitor system failure conditions (paragraph C) indicate contamination. The question of contamination instrumentation must be addressed in detail and resolved in the detailed design phase of the program.

V. SYSTEM COMPONENT SIZING

A. SIZE FOR NORMAL BOILOFF CONDITIONS

Normal boiloff conditions are defined as 400 gallons per day. Using the system analytical model, described in Section III, the baseline reliquefaction system was sized to meet this requirement. Because the cold box is located on the top of the dewar the size optimization process leaned toward cold box equipment sizes as small and lightweight as practical. The major equipment items of the cold box are the hydrogen high-temperature heat exchanger, the nitrogen gas high-temperature heat exchanger, the LN_2 heat exchanger, the J-T valve, the low-temperature heat exchanger, and the condenser. These items are housed in an evacuated pressure vessel.

B. SIZE TO ACCOMMODATE DEWAR LOADING AND POST LAUNCH CONDITIONS

The hydrogen losses after a Space Shuttle launch are defined in the contract statement of work to be 8500 pounds. This represents approximately 14,800 gallons. Dewar recovery periods of 12, 24, and 48 hours after launch are to be considered. Recovery is defined as a dewar thermodynamic state consistent with normal boiloff conditions. The estimated loss caused by loading the dewar with 400,000 gallons is approximately 8350 pounds. This loss is not defined in the statement of work; the calculations used to estimate this loss are given in Appendix A. The time available to condition the tank during loading is about nine days. Because the reliquefaction system size would have to be extrememly large to handle total post launch losses it was decided to size the "maximum" system to handle just the dewar loadings. Approximate sizes of the two limiting systems designs are given in Table V-1.

Table V-1 Thermal Model Major Component Sizes

	System 1	System 2
Compressor		
Number	1 or 2	4
Stages	3	3
Flow Rate	106 Scfm	106 Scfm
High-Temperature Heat Exchangers		
Number	2	2
Length	2.25 ft	5.67 ft
Inside Diameter	1.5 ft	1.5 ft
Outside Diameter	2.0 ft	3.43 ft
No. of Tubes	10	20
Diameter	3/16 in.	3/8 in.
Liquid Nitrogen Bath		
Length	3 ft	7.56 ft
Diameter	2 ft	2 ft
No. of Coils	2	7
Coil Diameter	1 ft	1 ft
Tube Diameter	1/2 in.	1 in.
Low-Temperature Heat Exchanger		
Length	3.0 ft	7.56 ft
Inside Diameter	0.625 ft	0.625 ft
Outside Diameter	1.25 ft	1.89 ft
No. of Tubes	14	14
Diameter of Tubes	1/4 in.	1/2 in.
Condenser		
Heat Transfer Surface Area	30.0 ft^2	132 ft^2
Cold Box		
Length	10.0 ft	15.0 ft
Diameter	4.0 ft	8.0 ft
Piping		
Line Diameter	1 in.	2 in.

System 1 sized to reliquify normal boiloff with no cycle venting.
System 2 sized to reliquify dewar loading boiloff with no cycle venting.

VI. SYSTEM FLOW DIAGRAM AND PARTS LIST

The system flow diagram is shown on Figure VI-1. The parts list is in Table VI-1.

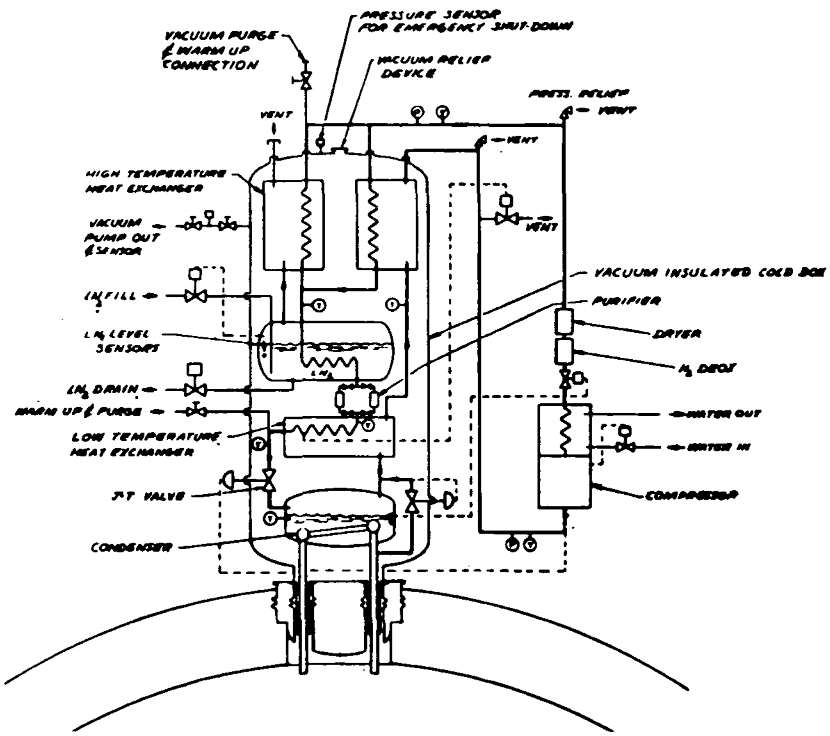


FIGURE VI-1 H_2 RELIQUEFACTION SYSTEM SCHEMATIC

Table VI-1 Parts List

1. 4-Stage Compressor	18. LH_2 Level Sensor (1 Required)
2. J-T Valve	19. Molecular Seive
3. GH_2 Resupply Valve	20. Molecular Seive (Nitrogen Removal)
4. Vent Valve	21. High-Temperature Heat Exchanger, GN_2
5. LN_2 Fill Valve	22. High-Temperature Heat Exchanger, GH_2
6. LN_2 Drain Valve	23. Low-Temperature Heat Exchanger
7. Pressure Relief Valve (High Press.)	24. LN_2 Heat Exchanger
8. Pressure Relief Valve (Low Press.)	25. Compressor Bypass Valve (3-Way)
9. Check Valve (2 Required)	26. Misc Bolts, Nuts, Etc.
10. Purge Valve (2 Required)	27. Thermal Insulation
11. Vacuum Valve (2 Required)	28. LN_2 Vessel
12. Vacuum Gage	29. LH_2 Vessel and Condenser
13. Water Control Valve	30. Cold Box
15. Temperature Sensor W/Remote Readout (6 Required)	31. Internal Interconnecting Tubing
	32. Piping from Cold Box to Compressor
16. Pressure Sensor W/Remote Readout (2 Required)	33. Piping from Compressor to Cold Box
17. LN_2 Level Sensor (2 Required)	34. Vacuum Filter System
	35. Control Panel with Temperature and Pressure Readout and Valve Controls

VII. SYSTEM COST ELEMENTS

A. CAPITAL INVESTMENT

An estimate of capital investment costs for a two-compressor reliquefaction system is given in Table VII-1. A detailed description of the implementation tasks and equipment costs are provided in Appendix E.

B. OPERATING COSTS

It is assumed that eight hours a week average will be required for operating cost. This activity will include taking data, checking the status of the reliquefaction system, and making adjustments on control settings. The operating labor rate is assumed to be $12 per hour.

C. MAINTENANCE COST

It is assumed that the compressors will require three overhauls per year. Also the overhaul will take three men one week per overhaul, a total of 360 man-hours per year. The maintenance labor rate is assumed to be $12 per hour. The maintenance materials are assumed to be $500/year.

D. ESCALATION RATES

Labor rates and water costs are assumed to escalate at 6% per year. Liquid nitrogen and electric power are assumed to escalate at 10% per year. There is a firm contract for the liquid hydrogen and therefore it should not escalate in price. However, computer runs were made to illustrate the effect of hydrogen escalation. This effect is graphically illustrated in Figure II-2.

Table VII-1. Budgetary Capital Investment Cost for Two-Compressor System

Design		$ 43,000
Materials & Subcontract		334,000
Fabrication & Assembly		28,000
Performance Test		39,000
Acceptance Test		8,000
Pack & Ship		8,000
Facility Modification & Installation		112,000
Startup and Checkout		25,000
Documentation and Reporting		10,000
	Total	$607,000

E. OPERATION PARAMETERS

The number of launches per year, hours associated with a launch, and the system operational life are considered as input variables. Special cases that varied the capital investment costs and escalated the cost of hydrogen were also analyzed. If a one compressor system is used, the system downtime was set at 5.8% per year. This is consistent with three overhauls per year. If two or more compressors are used, the downtime is assumed to be 1% per year. This assumption was made because one compressor will handle normal boiloff and therefore compressor overhaul can take place during normal boiloff time periods.

F. SAVINGS DATA

Current costs of expendables are assumed to be 0.03¢/gal for water, \$0.041/lbm for LN_2, \$0.024/kW-hr for electric power, and \$1.75/lbm for liquid hydrogen. The cost of liquid hydrogen was not escalated over the 15 year Shuttle Program.

VIII. LIFE-CYCLE COSTS

Summaries of life-cycle cost analysis results for baseline conditions are given in Tables VIII-1 and VIII-2. Baseline conditions are defined to be 20 Space Shuttle launches per year and a system life of 15 years. Detailed life-cycle cost data sheets for the conditions are outlined on Table VIII-1 and VIII-2. Detailed computer tables of the 132 combinations and variations of conditions are given in Appendix D.

Table VIII-1
*System Comparison Using Baseline Parameters (12 hour launch recovery time)**

System	No. of Comp	Vent Rate, %	Lifetime Hydrogen Savings, Million lb	Capitol Investment, Million $	Lifetime Saving, Million $
1	1	0	1.214	0.401	0.978
1	1	5	1.343	0.401	1.234
1	1	10	1.452	0.401	1.442
1	1	25	1.731	0.401	1.952
1	2	0	1.836	0.499	1.662
1	2	5	2.115	0.499	2.211
1	2	10	2.343	0.499	2.649
1	2	25	2.930	0.499	3.737
2	4	0	3.297	0.694	3.505
2	4	5	3.325	0.694	3.561
2	4	10	3.350	0.694	3.608
2	4	25	3.416	0.694	3.727

*Baseline Parameters:

20 Space Shuttle Launches & Dewar Loadings per year

15-Year Life

12-Hour Launch Recovery Time

Table VIII-2
*System Comparison Using Baseline Parameters (48-hour launch recovery time)**

System	No. of Comp	Vent Rate, %	Lifetime Hydrogen Savings, Million lb	Capital Investment, Million $	Lifetime Saving, Million $
1	1	0	1.214	0.401	0.978
1	1	5	1.364	0.401	1.277
1	1	10	1.491	0.401	1.519
1	1	25	1.818	0.401	2.116
1	2	0	1.934	0.499	1.786
1	2	5	2.260	0.499	2.425
1	2	10	2.526	0.499	2.937
1	2	25	3.211	0.499	4.207
2	4	0	3.654	0.694	3.988
2	4	5	3.765	0.694	4.211
2	4	10	3.864	0.694	4.399
2	4	25	4.127	0.694	4.878

*Baseline Parameters:

20 Shuttle Launches & Dewar Loadings per Year

15-Year System Life

48-Hour Launch Recovery Time

IX. PRELIMINARY DESIGN CONCEPT AND ANALYSES

The work presented in Section IX is the result of an add-on to the initial contract to develop detail design concepts and analyses for a hydrogen reliquefaction system sized for two compressors with twenty-five percent venting. This system is defined as System 1 in this section, and System 1 or Case 1 in the preceding sections. Structural analyses were also performed on System 2, which is sized for four compressors with twenty-five percent venting. Component size information used in this section was developed by the computer analyses in the preceding sections and is summarized in Table V-1.

The objectives of the add-on study were to develop a detail configuration for the cold box, develop a concept for installing the cold box on the existing 850,000 gallon liquid hydrogen dewar at LC-39, develop a plan for penetrating the LH_2 dewar, analyze the heat leak at the penetration area, develop a control system concept for safing the system, and determine the practical feasibility of the liquid hydrogen reliquefaction concept.

The work was performed in four basic tasks consisting of:

- Task I - Structural Analyses of the Cold Box
- Task II - Detail Plan for Penetrating the LH_2 Dewar
- Task III - Detail Heat Leak Analysis of the LH_2 Dewar Penetration
- Task IV - Detail System Safety and Control Study

The results of the add-on study indicate that the hydrogen reliquefaction system can be incorporated on the existing liquid hydrogen dewar without compromising the system operation or safety. Minor structural additions are required to the outer shell of the dewar to spread the loads imposed by the cold box. The dewar penetration is fairly simple and can be designed so that there is virtually no heat loss. The control system will automatically shut the reliquefaction system down in the event of any equipment malfunction. During automatic shutdown, the reliquefaction system is placed in a passive condition and the LH_2 dewar operation is the same as if the reliquefaction system were not present.

An informal review of the closed loop refrigeration concept and condenser design was conducted at the National Bureau of Standards (NBS) with Mr. J. Hord and cognizant cryogenics personnel. The opinion of the NBS personnel was that the system would work as designed. NBS suggested a method of obtaining a lower precooling temperature by replacing the Joule-Thomson valve with an ejector design that they have used in both nitrogen and helium cryogenic refrigeration systems. It was indicated that the use of the ejector could lower the temperature sufficiently to allow the system to operate at a dewar pressure of 15 psia. This approach appears to have merit, but requires study beyond the scope of the present program for incorporation.

A. TASK I - STRUCTURAL ANALYSIS OF THE COLD BOX

Analyses were performed to determine the ability of the KSC liquid hydrogen dewar to support the cold box. The key activities supporting this task consisted of developing the size, shape and weight of the cold box, determining the cold box wind loads, determining the method of attachment to the dewar, determining functional access requirements and determining if the dewar outer shell has the capability to support the total cold box loads.

The analyses show that addition of structure to spread the load over the LH_2 dewar outer shell and guy wires or stiffening rods are required to eliminate concentrated bending loads and to minimize wind-induced vibration. This addition, however, is minor and has insignificant effect on the overall system cost.

The structural analyses were performed for both System 1 and System 2.

1. Cold Box Size and Weights Analysis

Using the results of the computer program which determined the size of the system components, reference Table V-1, a conceptual design depicting the size and shape of each of the components within the cold box was produced. Assembly layouts and packaging studies were made to develop a minimum size cold box. The resulting concept design for the system components and the cold box for System 1 and System 2 is defined by the following drawings. These drawings are included herein as Appendix F.

System 1 Design

Drawing	Description
EPL6301645	Layout-Cold Box H_2 Reliquefaction
EPL6301647	Heat Exchanger-High Temp. GN_2 and LN_2
EPL6301648	Heat Exchanger-High Temp. H_2 Reliquefaction
EPL6301649	Heat Exchanger-Low Temp. H_2 Reliquefaction
EPL6301650	Layout-LH_2 Condenser, H_2 Reliquefaction

System 2 Design

Drawing	Description
EPL6301651	Layout-Cold Box H_2 Reliquefaction
EPL6301653	Heat Exchanger-LN_2 Bath, H_2 Reliquefaction
EPL6301654	Layout-LH_2 Condenser, H_2 Reliquefaction
EPL6301655	Heat Exchanger-High Temp. H_2 Reliquefaction
EPL6301656	Heat Exchanger-Low Temp. H_2 Reliquefaction

The cold box assembly weight was determined by performing a detail weight analysis of each of the system components and the cold box. Component and total system weight for System 1 and System 2 is summarized in Table IX-1.

Table IX-1. Weight Summary

Component	System 1	System 2
Cold Box	2,401 lb	7,982 lb
High Temp. GN_2 and LN_2 Heat Exchanger	836	1,262
High Temp. H_2 Heat Exchanger	500	6,054
Low Temp. Heat Exchanger	568	1,860
Condenser	409	1,424
Hydrogen Purifier	400	800
Misc. Hardware (Valves, Plumbing and Supports)	266	721
Total	5,380 lb	20,103 lb

2. Cold Box Wind Loads and Dewar Stress Analysis

A stress analysis was performed to determine capability of the LH_2 dewar to support the H_2 reliquefaction system cold box. Both System 1 and System 2 configurations were analyzed. The stress analysis is provided in Appendix G.

1) Discussion - The LH_2 dewar outer shell requires strengthening for both systems. Wind loading and blast pressure loading analyses were conducted for each system with the blast pressure of 2.0 psi being critical. The analyses show that stain-

less steel guy wires or stiffening rods are necessary to eliminate concentrated bending loads into the dewar shell and to minimize wind induced vibrations. Since the original LH_2 dewar analysis was not available, it was necessary to determine the existing stress levels and critical buckling levels of the dewar outer shell, i.e., prior to installation of the cold box, without apex loading. Several methods were investigated to envelope a range of buckling pressures. A critical apex load to produce buckling was then determined and a straight line interaction formula was used to combine the loading. A factor of safety of 1.5 was utilized in the load combinations.

The ASME code stress intensity requirements of paragraph AD 140 were also satisfied throughout the analysis. The code uses maximum shear theory failure and allows a maximum stress intensity of 16,700 psi when compared to the primary principal stresses at a given location.

A listing of symbols used in this stress analysis is provided at the end of this section.

2) Summary of Dewar Modifications for System 1

The stress analysis shows that the following modifications to the LH_2 dewar are required to support the System 1 cold box design.

- Add 4 guy wire cables or stiffening rods (1/4 DIA - 1 x 19 stainless steel) pretensioned to 2770 pounds each, locate so that blast pressure condition is 45° off the cables.

- Add 11/16 plate x 6.00 inch high rolled frame at 68 inch diameter around the existing manhole cover.

- Add 11/16 plate stiffeners radially from manhole to 68-inch diameter frame between every other manhole flange bolt.

- Add 11/16 plate stiffeners that extend out from the 68-inch diameter frame.

- It would be desirable to make modifications with the dewar at ambient pressure so that the new and existing structure will be more efficiently utilized. The dewar may be modified, however, without breaking the vacuum.

3) Summary of Dewar Modifications for System 2

The stress analysis shows that the following modifications to the LH_2 dewar are required to support the System 2 cold box design.

- For this analysis, additional external stiffeners will be extended outward to the * 9-7 internal frame.

- The external stiffeners used in this analysis are W6x25 members rolled to the outer sphere 420 inch radius.

- An additional 11/16 plate collar is carried from 23 to 44 inch radius. Plug welds should be included.

- A rolled ring frame of 68-inch diameter is added over the new collar to interface with the cold box.

- Six guy wires connected at points tangent to the dewar sphere are required for minimum preload (3/8-in diameter 7x7 or 7x19 can be used). The cables should be loaded before installation to break in and pre-tensioned to 3,960 pounds at installation.

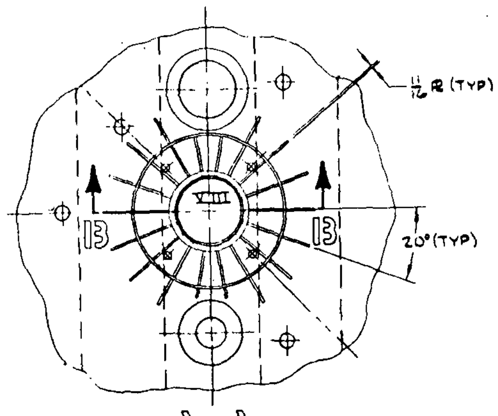
- It is desirable but not mandatory that modifications be incorporated with the dewar at ambient pressure.

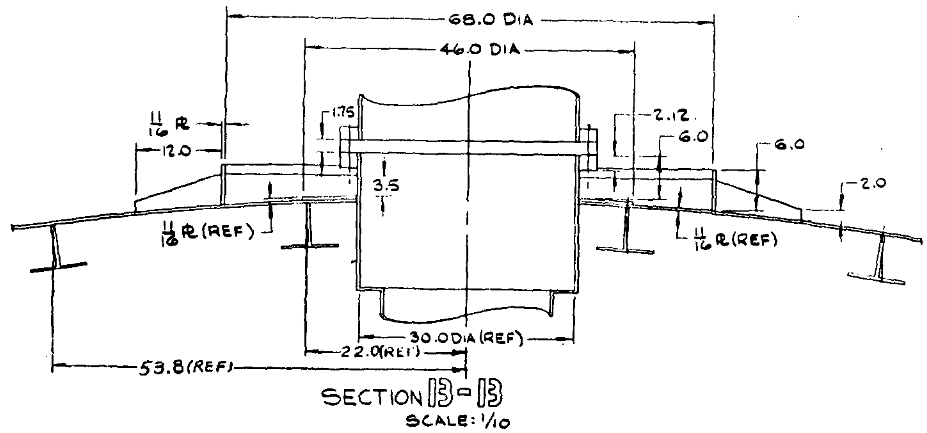
3. Dewar Modification and Cold Box Installation Design

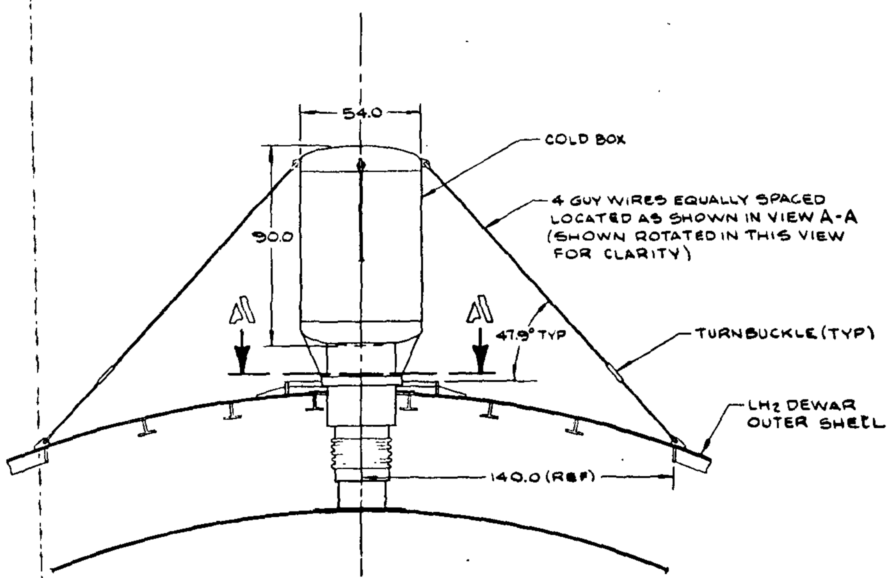
Structural modification to spread the load on the dewar resulting from the cold box installation is required for both Systems 1 and 2.

A conceptual design of the structural modifications for the System 1 cold box is depicted in Figure IX-1. The support system consists of a 68-inch diameter ring located concentric with the manhole and radial gussets connecting the manhole flange to the ring and extending 12 inches beyond the ring. The ring and the radial gussets are welded to the outer shell of the Dewar and to the manhole flange. It is anticipated that the supporting structure can be welded to the dewar outer shell without breaking the dewar vacuum. It is more desirable, however, from a stress standpoint, that the dewar vacuum annulus be near ambient pressure during welding.

*Refer to CBI Contract No. 9-3293- and 4, Dwg. 1A for identification of the existing 9-7 internal frame.







NOTES:

1. GUSSET MATL. TO BE A285-C FBX.
2. WELDING OF THE STIFFENERS TO THE DEWAR OUTER SHELL MAY BE ACCOMPLISHED WITHOUT BREAKING THE VACUUM. A SCHEDULE OF INTERMITTANT WELDING MUST BE DEVELOPED TO PREVENT DAMAGE TO THE OUTER SKIN.
3. TRIM PLATES TO MATCH CONTOUR OF TANK.
4. GUY WIRES TO BE ATTACHED AND ORIENTED TO BLAST DIRECTION AS SHOWN. PRETENSION EACH CABLE TO 2771 LBS.
5. MK. NOS. (XIII, ETC.) ARE PER C.B.I. CONTRACT NO. 9-529314, DWG. 1A.

Figure IX-1 Cold Box Installation and Dewar Modification, System 1

The cold box is attached to the dewar by a bolted connection at the existing flange. The method of penetrating the inner shell of the dewar is discussed in Paragraph IX-B. Four guy wires, oriented as shown, and pretensioned to 2770 pounds are used to provide the stiffness required to preclude fatigue loading due to the wind or launch overpressure.

The design concept for the structural support system for System 2 is depicted in Figure IX-2. This system consists of extending the existing 11/16-inch x 46-inch diameter collar at the manhole to 88-inches diameter. A 68-inch diameter stiffening ring is added over the collar and radial stiffeners are added that extend to the existing 280-inch diameter support ring. Six pretensioned guy wires are used to provide the required stiffness to preclude wind or blast-induced oscillations.

4. Functional Access Requirements

No access is required to the inside of the cold box for system operation or routine maintenance. The cold box is an all-welded system with valve bonnets extending outside the shell. Thus, valve maintenance can be performed from the outside.

During installation, access for torquing the flange bolts on the penetration line is through access holes in the cold box support structure. Access to the vacuum valve for the penetration area is also through these holes. After cold box installation sheet metal covers are installed over the access holes.

B. TASK II - DETAIL PLAN FOR PENETRATING DEWAR

The existing dewar manhole configuration is depicted in Figure IX-3. The manhole at the top of the dewar is sealed with a blind flange on the vacuum jacket shell and an inverted pipe cap (dish shaped closure) over the inner shell. Relative motion between the inner and outer dewar shells is accommodated by an expansion bellows in the cylindrical section connecting the inner shell to the outer shell. The cylindrical section is vacuum insulated but is not common to the vacuum annulus of the dewar.

This section describes the plan for connecting the cold box to the hydrogen dewar by penetrating the manhole.

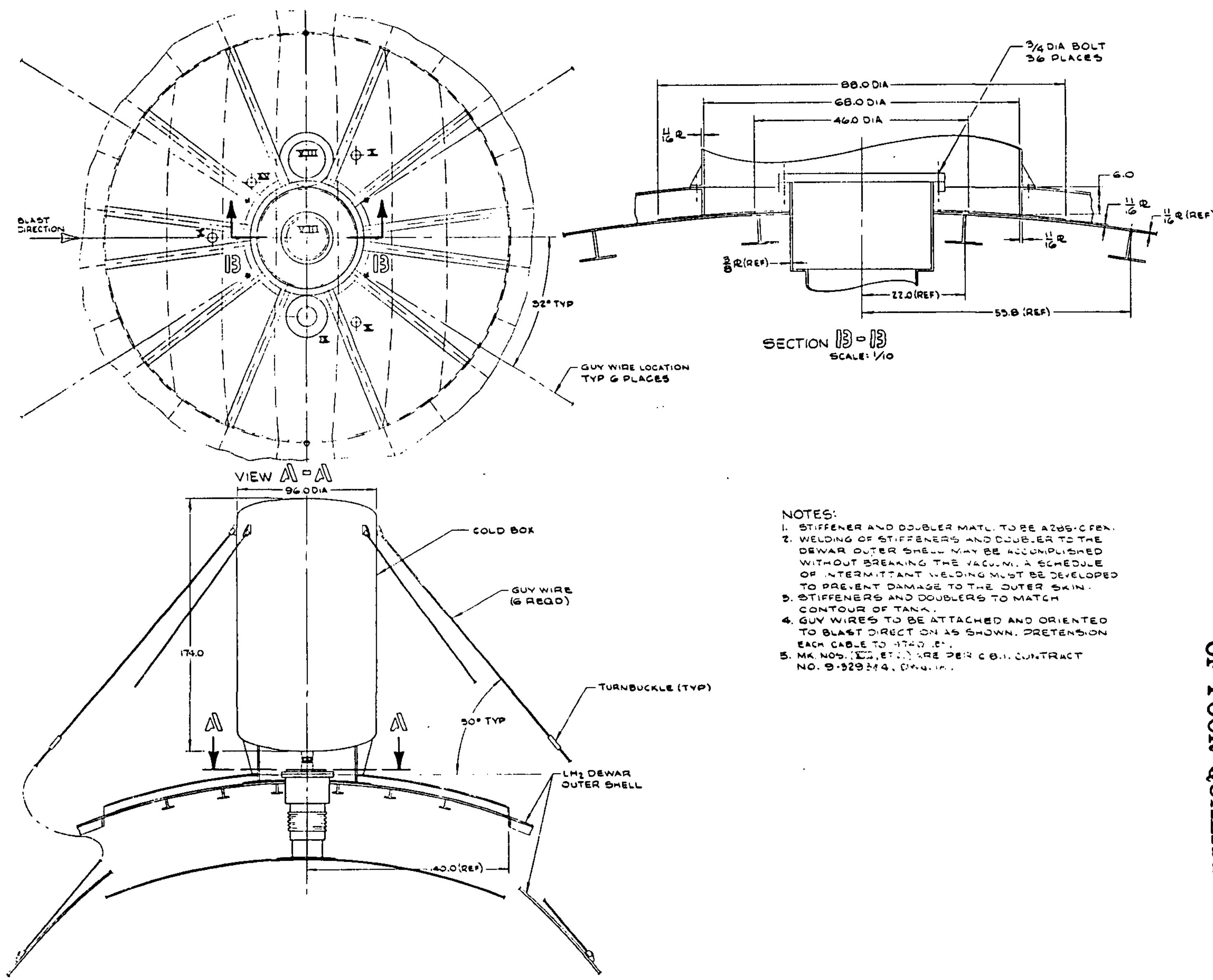


Figure IX-2 Cold Box Installation and Dewar Modification, System 2

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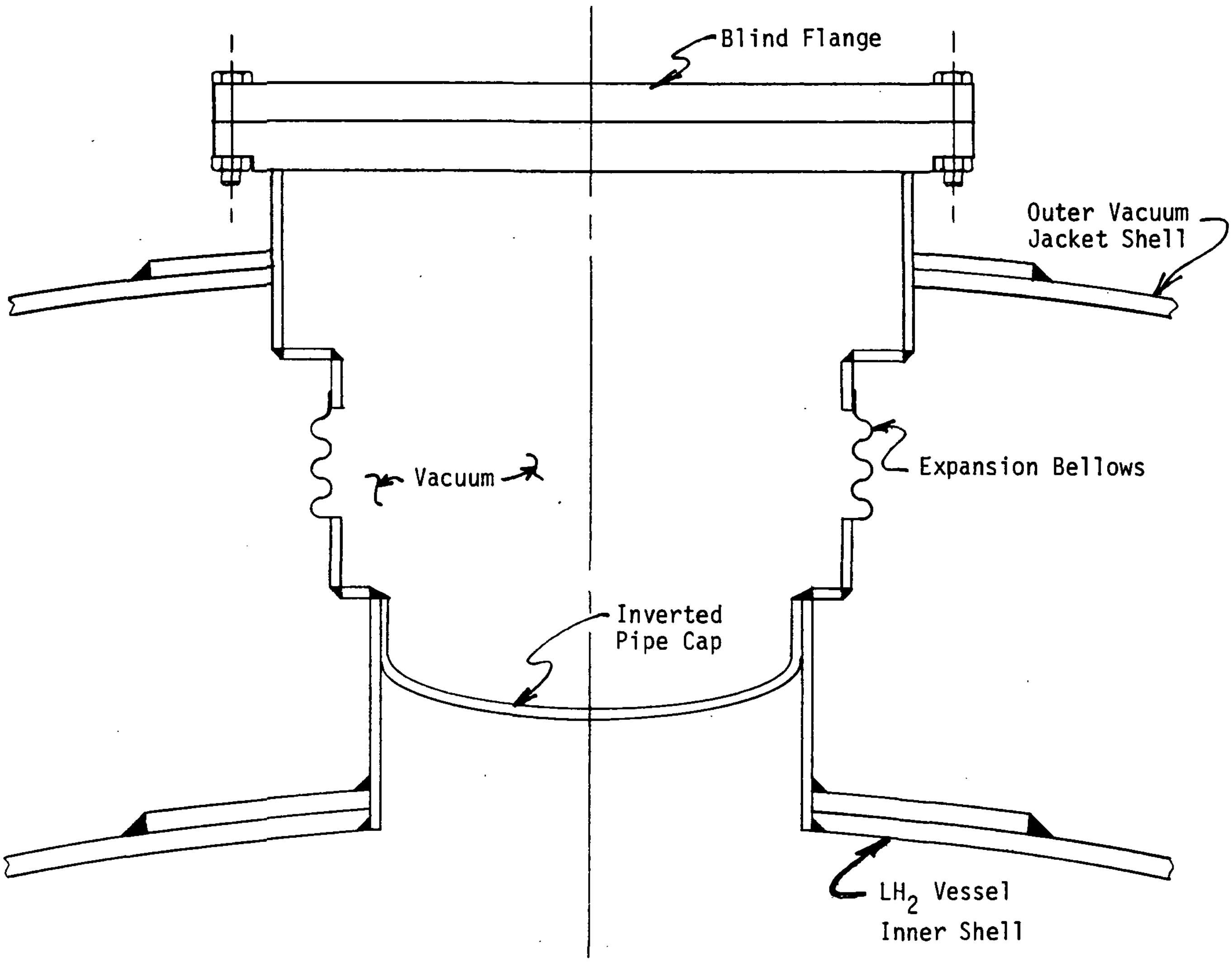


FIGURE IX-3. EXISTING LH_2 DEWAR MANHOLE CONFIGURATION

1. Design Considerations

The key considerations in the dewar penetration design are listed as follows:

1) The structural and vacuum integrity of dewar must be maintained.

2) The cleanliness of the dewar must be maintained.

3) Capability must be provided to compensate for misalignment and installation tolerances.

4) Capability must be provided in the lines that penetrate the liquid hydrogen vessel to accommodate the relative motion between the inner and outer dewar shells.

5) The penetration must be designed to minimize the thermal losses and not to degrade the reliquefaction capability of the system.

6) The penetration design must consider the accessibility required for ease of installation.

7) The penetration design must be such that the dewar can be returned to its original configuration upon removal of the reliquefaction system.

8) The temperature at any locations where gaskets are used must be compatible with the gasket material to assure sealing.

2. Penetration Design Description

The manhole penetration design is depicted in Figure IX-4.

Modification to the existing manhole closures is similar for both Systems 1 and 2. The modification consists of cutting a penetration hole in the blind flange and the inverted pipe cap and connecting these two closures with a pipe. An expansion bellows is used in the connecting pipe to compensate for relative motion between the two closures. The pipe is welded to the pipe cap over the inner vessel and sealed with double O-rings on the underside of the blind flange over the outer shell.

The GH_2 inlet and the LH_2 outlet lines are concentric tubes routed from the condenser in the cold box through the connecting pipe to the hydrogen storage vessel. The GH_2 inlet line is vacuum insulated common to the vacuum in the cold box. Thirty layers of

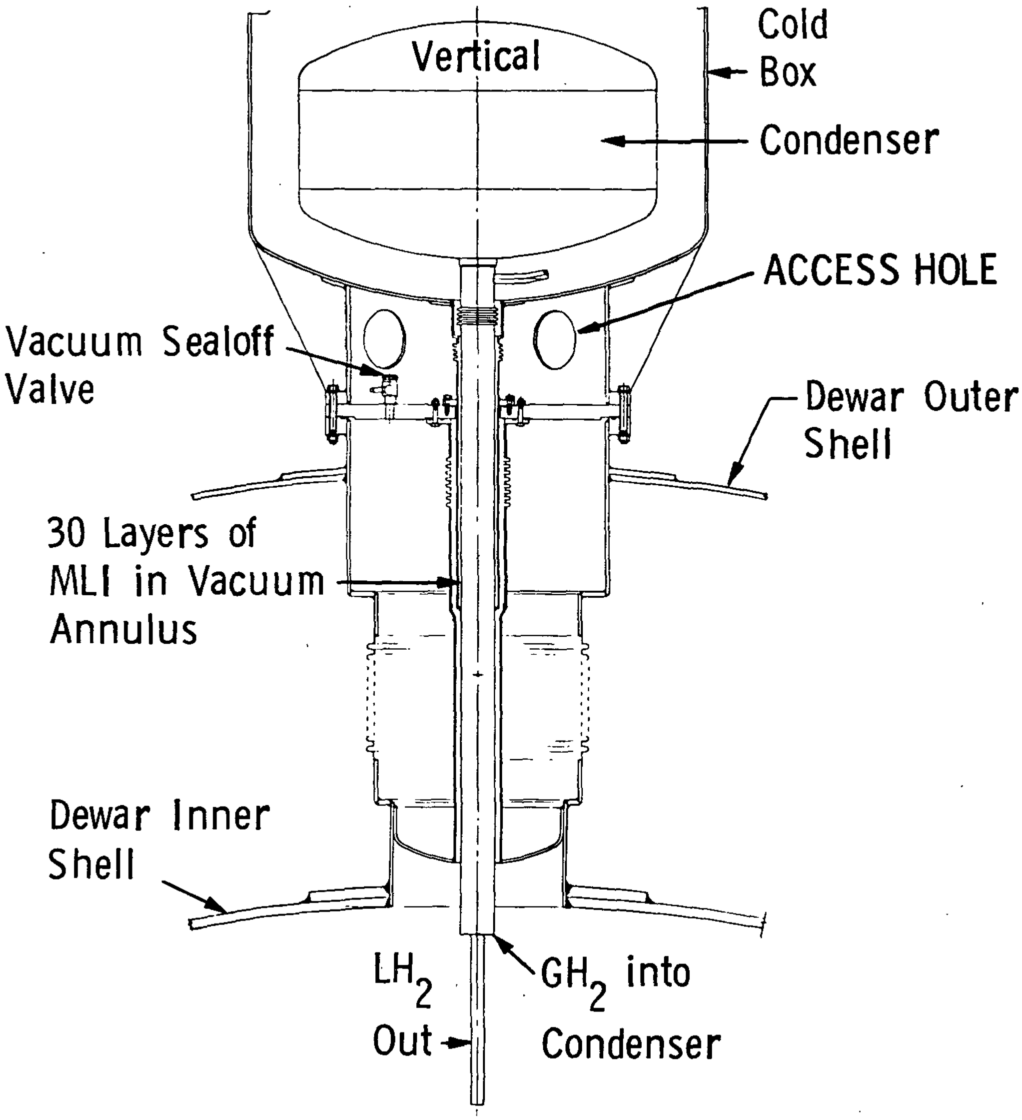


FIGURE IX-4. LH_2 DEWAR PENETRATION

multilayer insulation are used in the vacuum annulus over the GH_2 inlet line to minimize the thermal losses.

The cold box is attached structurally to the blind flange using the existing bolt holes and sealed at the center hole with a flange and O-ring. Expansion bellows are used in the vacuum jacket and condenser line to allow for misalignment and thermal contraction.

3. Installation Procedure

1) Break the vacuum in the cylindrical section connecting the inner and outer Dewar shells.

2) Remove top manhole cover.

3) Remove pipe cap over inner shell by grinding away the weld.

4) Perform machining operations on the two closures (cut holes, preparation for welding, and finish surfaces for sealing).

5) Weld connecting pipe to inverted pipe cap. This is to be done in the shop where good alignment can be assured.

6) Reinstall inverted pipe cap and reweld to inner vessel port.

7) Install blind flange and seals.

8) Install cold box and seal.

C. TASK III - DETAILED HEAT LEAK ANALYSIS

The heat leaks in the closed-loop hydrogen refrigerator system were analyzed with particular attention to the losses at the penetration between the cold box and the dewar. The MITAS II (Martin Marietta Interactive Thermal Analysis System) was used to model the heat transfer system under study.

1. Thermal Analysis Approach

The primary heat leaks in the cold box/dewar penetration were found to be by radiation and convection heat transfer.

1) Radiation - The radiation heat transfer is given by:

$$\dot{Q} = \mathcal{F} \sigma A_1 \left(T_1^4 - T_2^4\right)$$

$$\mathcal{F} = \frac{1}{\frac{1}{F_{21}} + \left(\frac{1}{\epsilon_1} - 1\right) + \frac{A_1}{A_2}\left(\frac{1}{\epsilon_2} - 1\right)}$$

$$F_{21} = \frac{A_1 F_{12}}{A_2}$$

where: σ = 0.1714×10^{-8}, BTU/hr-ft^2 - $^\circ F^4$ (Stefan - Boltzman Constant)

ϵ = Emissivity of the surface

$\dot{Q}$ = Heat transfer, BTU/hr

$\mathcal{F}$ = Radiation Exchange Factor

A_1 = Area, Ft^2

A_2 = Area, Ft^2

F_{12} = Radiation view factor

F_{21} = Radiation view factor

2) Convection - The convection heat transfer is given by:

$$\dot{Q} = hc\, A_2 \, (T_1 - T_2)$$

where: hc = surface convection coefficient, BTU/hr-ft^2-$^\circ$F

3) Conduction - Conduction heat transfer in the penetration tubes was also considered but was not a significant source of heat leakage. The conduction losses are given by:

$$\dot{Q} = \frac{kA}{\Delta x} (T_1 - T_2)$$

where: k = thermal conductivity, BTU/hr-ft-$^\circ$F

Δx = distance between locations 1 and 2

A = area normal to heat transfer, Ft^2

2. Computer Model and Analysis Results

A computer model of the cold box penetration was developed. The penetration area was divided into twelve levels or nodes as illustrated in Figure IX-5. The nodes and the conductors shown in Figure IX-6, made up the computer model of the penetration area and was programmed into MITAS II.

The first computer run assumed an air temperature of 85°F and the length of the vacuum jacket on the penetration pipe was 36.5 inches. The results of this run showed that the heat leak was sufficient to completely vaporize the liquid hydrogen returning to the Dewar.

The second computer run assumed an air temperature of 85°F, but the vacuum jacket was extended to 56.5 inches. This run also showed that there was sufficient heat reaching the liquid hydrogen pipe to completely vaporize the returning liquid hydrogen.

The major heat leak identified in the first two runs was caused by radiation. For the third run, thirty layers of multilayer insulation were added inside the vacuum jacket. The air temperature was again assumed to be 85°F, and the vacuum jacket length was maintained at 56.5 inches. The multilayer insulation extended 54.5 inches into the vacuum jacket. This configuration proved to be successful in reducing the radiation heat leaks with only an extremely small loss of the liquefied hydrogen. A fourth run was made using the same configuration, and outside air temperature of 105°F. Under these conditions, the boiloff of the returning liquid hydrogen was about the same as with the 85°F ambient.

Table IX-2 shows the heat transfer into and out of each node of the model for the 105°F ambient condition. The total heat into the liquid hydrogen is found to be 5.7806×10^{-4} Btu/hr. From this, the actual amount of boiloff can be determined as follows:

$$\dot{Q} = 5.7806 \times 10^{-4} \text{ BTU/hr}$$

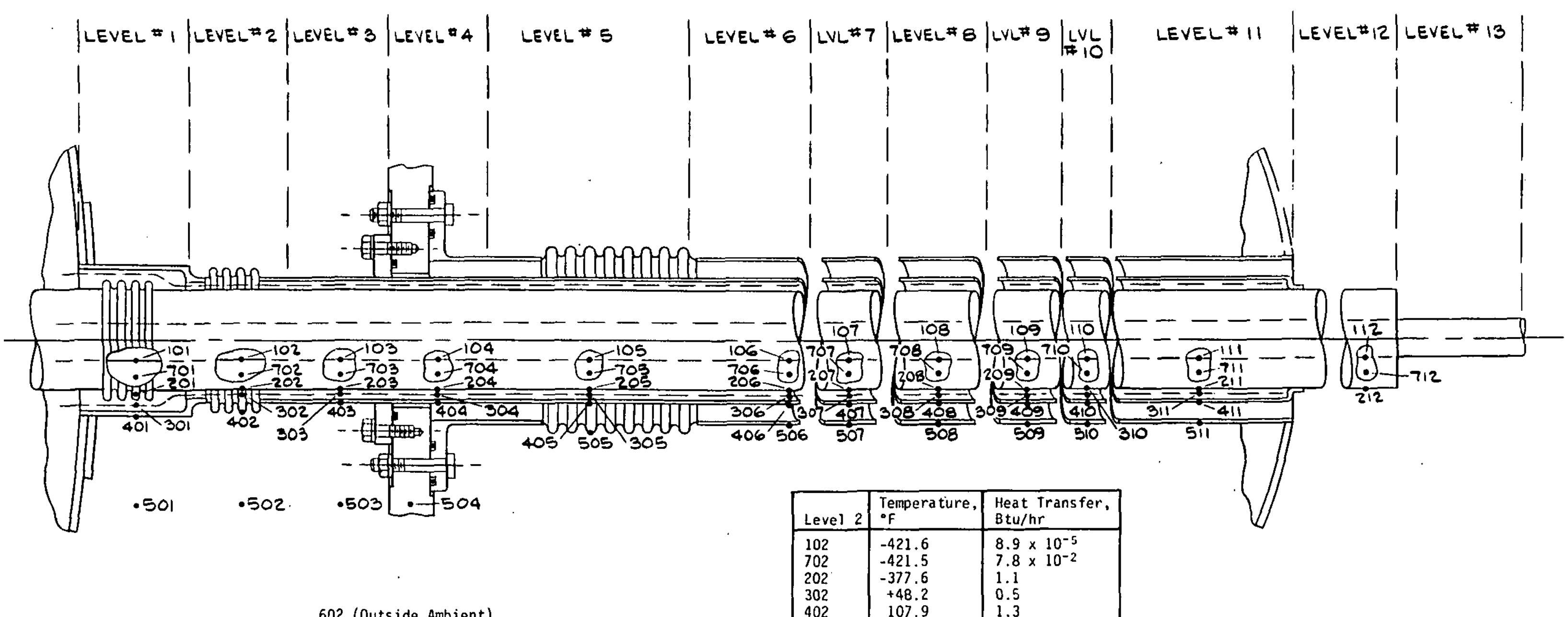
$$\dot{m} = 9.583 \text{ LBm/hr}$$

$$\text{heat leak/LBm of } H_2 = \frac{5.7806 \times 10^{-4}}{9.583} \quad \frac{\text{BTU/hr}}{\text{LBm/hr}}$$

$$6.0321 \times 10^{-5} \text{ BTU/LBm}$$

$$\text{hfg} = 189.117 \text{ BTU/LBm}$$

$$\text{Percent by mass vaporized} = \frac{6.0321 \times 10^{-5} \times 100}{189.117} = 3.19 \times 10^{-5}\ \%$$



Level 2	Temperature, °F	Heat Transfer, Btu/hr
102	-421.6	8.9×10^{-5}
702	-421.5	7.8×10^{-2}
202	-377.6	1.1
302	+48.2	0.5
402	107.9	1.3
502	104.5	10.1
602	105	1.6

Figure IX-5. LH_2 DEWAR PENETRATION - IDENTIFICATION OF LEVELS AND NODES USED IN THERMAL MODEL

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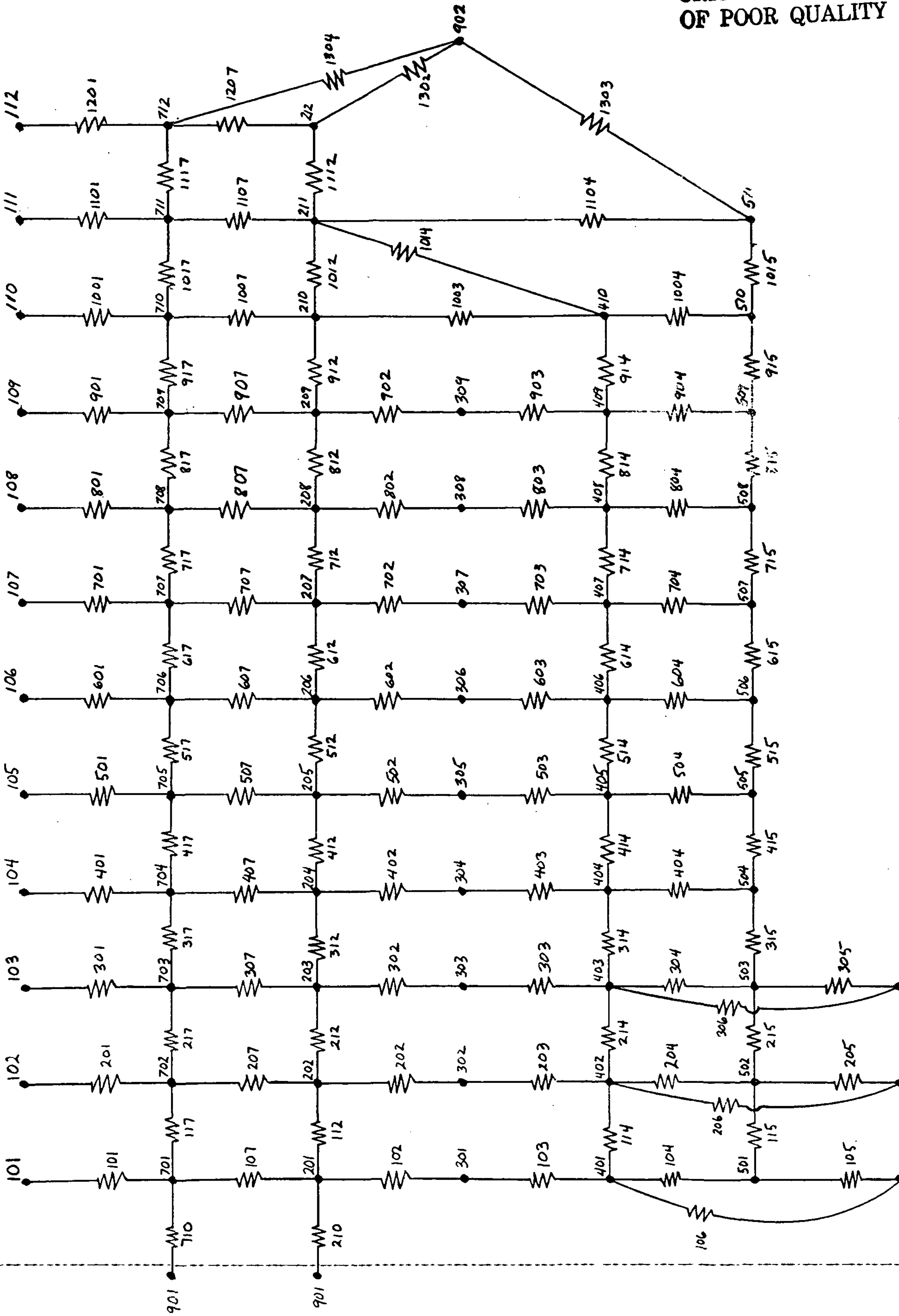

Figure IX-6 Computer Model of Dewar Penetration

Table IX-2 Heat Transfer and Temperature Profiles for Dewar Penetration (assuming 105°F exterior environment)

	Level-1	Level-2	Level-3	Level-4	Level-5	Level-6	Level-7	Level-8	Level-9	Level-10	Level-11	Level-12	Total
Node	101	102	103	104	105	106	107	108	109	110	111	112	
LH_2 Pipe, Q_I	8.9106×10^{-5}	8.9608×10^{-5}	8.3314×10^{-5}	7.5138×10^{-5}	5.2586×10^{-5}	4.6821×10^{-6}	4.0851×10^{-5}	3.4557×10^{-5}	3.4946×10^{-5}	2.3213×10^{-5}	7.6951×10^{-6}	2.2911×10^{-7}	5.7806×10^{-4}
T	-421.6	-421.6	-421.6	-421.6	-421.6	-421.6	-421.6	-421.6	-421.6	-421.6	-421.6	-421.6	
Node	701	702	703	704	705	706	707	708	709	710	711	712	
GH_2, Q_I	3.8363×10^{-2}	7.8924×10^{-2}	9.9130×10^{-2}	1.0990×10^{-1}	8.9674×10^{-2}	9.2757×10^{-2}	9.7824×10^{-2}	1.0597×10^{-1}	1.4475×10^{-1}	1.5549×10^{-1}	1.2725×10^{-1}	3.6332×10^{-3}	1.444
GH_2, Q_O	-3.7870×10^{-2}	-7.7730×10^{-2}	-1.0093×10^{-1}	-1.0986×10^{-1}	-8.9636×10^{-2}	-9.2804×10^{-2}	-9.7835×10^{-2}	-1.0592×10^{-1}	-1.4476×10^{-1}	-1.5547×10^{-1}	-1.2728×10^{-1}	-3.6331×10^{-3}	-1.1437
T	-421.5	-421.5	-421.5	-421.5	-421.5	-421.5	-421.5	-421.5	-421.5	-421.5	-421.5	-421.5	
Node	201	202	203	204	205	206	207	208	209	210	211	212	
GH_2 Pipe, Q_I	1.6874	1.1430	7.8459×10^{-1}	4.5433×10^{-1}	1.6095×10^{-1}	1.6383×10^{-1}	2.1125×10^{-1}	2.9143×10^{-1}	4.2639×10^{-1}	5.7301×10^{-1}	3.2326	2.3052	11.4340
GH_2 Pipe, Q_O	-1.6874	-1.1430	-7.8450×10^{-1}	-4.5440×10^{-1}	-1.6099×10^{-1}	-1.6380×10^{-1}	-2.1093×10^{-1}	-2.9197×10^{-1}	-1.2597×10^{-1}	-5.7290×10^{-1}	-3.2325	-2.3052	-11.1336
T	-401.7	-377.6	-363.0	-355.6	-353.3	-350.3	-345.5	-337.5	-328.5	-319.6	-302.6	-419.5	
Node	301	302	303	304	305	306	307	308	309	310	311	312	
MLI, Q_I	0.6229	0.4583	0.4401	0.3830	9.0036×10^{-2}	5.0747×10^{-2}	2.5256×10^{-2}	1.0272×10^{-2}	8.963×10^{-3}				2.0896
MLI, Q_O	-0.6229	-0.4583	-0.4401	-0.3830	-9.0001×10^{-2}	-5.0723×10^{-2}	-2.5247×10^{-2}	-1.0215×10^{-2}	-8.9784×10^{-3}				-2.0895
T	49.4	48.2	43.1	26.1	46.0	-21.3	-91.0	-164.2	-259.9				
Node	401	402	403	404	405	406	407	408	409	410	411	412	
Vac. Jac., Q_I	9.3075×10^{-1}	1.3066	3.4776	3.1606	2.8227	2.8165	2.9308	3.1917	3.4040	3.3950			27.4363
Vac. Jac., Q_O	-9.3074×10^{-1}	-1.3066	-3.4773	-3.1603	-2.8226	-2.8164	-2.9300	-3.1928	-3.4039	-3.3950			-27.4356
T	103.6	102.9	97.3	78.3	52.3	-15.9	-86.5	-160.6	-241.9	-275.1			
Node	501	502	503										
Air, Q_I	0.8159	1.4300	10.136										12.3819
Air, Q_O	-0.8159	-1.4299	-10.137										-12.3828
T	104.7	104.5	101.5										
Node				504	505	506	507	508	509	510	511	512	
Vac. Jac., Q_I				8.0641	7.9407	7.8953	7.8114	7.6463	7.3592	7.1660	7.5270		61.4100
Vac. Jac., Q_O				-8.0640	-7.9407	-7.8953	-7.8113	-7.6462	-7.3591	-7.1660	-7.5270		-61.4096
T				98.9	56.1	-8.6	-71.6	-133.3	-192.6	-284.6			
Node	601	602	603										
Cold Box Sup, Q_I													
Cold Box Sup, Q_O	-0.9793	-1.5957	-10.0468										-12.6318
T	105	105	105										

LEGEND: Q_I = Heat flow in (Btu/hr)
Q_O = Heat flow out (Btu/hr)
T = Temperature (°F)
For node and level identification refer to Figure IX-2.

therefore there is only a very small fraction of liquid hydrogen vaporized.

3. Conclusion

The cold box penetration insulation scheme with a vacuum jacket 56.5 inches long and 30 layers of multilayer insulation 54.5 inches long proved to be very effective. It should be noted that the extremely small heat leak to the liquid is due to the hydrogen gas which jackets the liquid line. This flow gas intercepts the heat transfer before it can effect the liquid.

D. TASK IV - DETAILED SYSTEM SAFETY AND CONTROL STUDY

1. Control System

The key functions of the control system include:

- Maintaining the required pressure in the condenser.

- Maintaining the proper liquid level in the condenser.

- Maintaining the required liquid level in the LN_2 heat exchanger.

- Maintaining the required pressure upstream of the J-T valve.

- Maintaining the required pressure on the suction side of the compressors.

- Automatic system shutdown in the event of equipment failure or loss of electrical power.

The control system concept is depicted schematically in Figure IX-7 and is discussed in the following paragraphs.

1) Condenser Pressure - For efficient operation of the refrigeration system the temperature in the condenser must be maintained at least $1^{o}F$ colder than the temperature in the LH_2 dewar. Thus the condenser pressure must be maintained around 12 psia, assuming the dewar pressure is 15 psia. The minimum condenser pressure, 10 psia, is set by the operational requirements of the compressor.

   The condenser pressure is controlled directly with two valves, the GH_2 inlet valve which admits GH_2 from the dewar to raise the pressure and a vent valve which vents the system at the upper pressure limit. The vent valve is located in the com-

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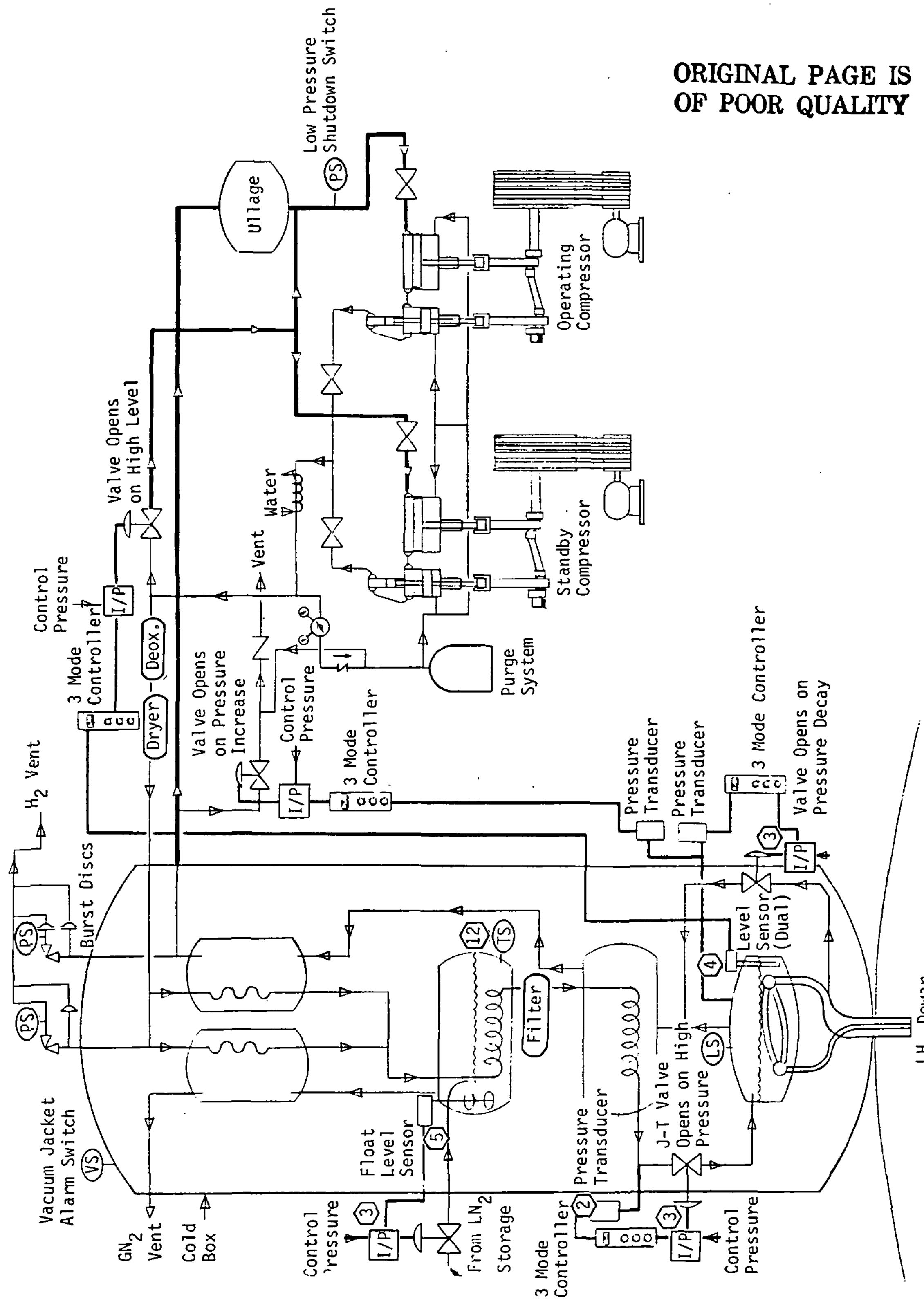

Figure IX-7 Hydrogen Reliquefaction Control System Schematic pressor suction line between the counter-flow heat exchanger and the compressor and is also used during system start-up to cool the low temperature heat exchanger. During automatic operation these two valves are interlocked so that they cannot be opened simultaneously. A manual control provides capability for both valves to be opened for system start-up or other non-automatic control operation. During automatic operation, the valves will have a dead space when they are both closed.

Two industrial type pressure transducers are used as the sensing elements for the valve controllers. The pressure transducers provide the input signal to two three-mode controllers which provide output signals to control the valves. The H_2 inlet valve opens at 11.5 psia and closes at 13 psia. The vent valve opens at 14.2 psia and closes at 13 psia. Thus, the condenser pressure is controlled between 11.5 psia and 14.2 psia. Once the system is stabilized during normal operation, the condenser will operate between 11.5 and 14 psia and the two control valves will remain closed. Control of the liquid level in the condenser causes the system to seek stabilization.

2) Condenser Liquid Level Control - The liquid hydrogen level in the condenser must be maintained at a level that covers the refrigeration tubes, but the tolerance on the liquid level can be up to $\pm$ 3 inches. This gives the control system considerable latitude in which to operate. The liquid hydrogen level is controlled by a liquid level sensor that controls a by-pass valve in the compressor discharge system. As the liquid level approaches the high level set point, the control by-pass valve begins to open which allows a portion of the compressor discharge gas to enter the compressor suction line. This reduces system flow to the J.T. valve and slows the rate of liquid hydrogen input to the condenser. This continues until a stable liquid level is achieved. When the liquid level falls to the low level set point the by-pass valve is closed and the full compressor discharge gas flows to the J.T. valve increasing the rate of liquid hydrogen input to the condenser until a stable liquid level is achieved.

The control feedback element is a capacitance level sensor, which provides a continuous level indication of the required accuracy. Hydrogen exhibits a 22% change in dielectric constant from liquid to gas, a capacitance probe of sufficient size is easily capable of determining the liquid level. A three mode controller accepts the level signal and provides the drive signal for the by-pass valve operation.

3) Liquid Level in LN_2 Heat Exchanger - The LN_2 heat exchanger liquid level is controlled by filling through a "bang-bang" type valve responding to two float switches, one for low level indication and one for high level indication. The LN_2 valve opens when the low level switch is activated and closes when the high level float switch is activated. This heat exchanger is vented through a counter-flow heat exchanger. In order to operate the LN_2 heat exchanger as close to atmospheric pressure as possible, the vent line is not valved or restricted in any way. Thus no pressure control of the LN_2 heat exchanger is required.

4) Joule-Thomson Valve Control - The Joule-Thomson valve will be set at a minimum opening when the system is placed in operation. A pressure transducer monitors the high pressure side of the system. During periods of normal operation, the pressure will vary in response to the compressor control and the J.T. valve will remain at a fixed opening. If the system high pressure exceeds the high pressure setpoint, the J.T. valve will be opened further to reduce this pressure. The valve action will be controlled by the three-mode controller. The pressure transducer will provide the input signal and the controller will provide the valve signal.

5) Compressor Suction Pressure - Compressor suction pressure is the same as condenser pressure minus the line pressure drop of approximately 1 psi. The compressors will operate efficiently at pressures between 9 and 16 psia. An ullage volume is provided to minimize suction pressure fluctuation. A low pressure switch shuts down the compressors and initiates automatic system shutdown in the event that suction pressure falls below 9 psia.

2. <u>Safety Features and Failure Modes and Effects Analysis</u>

1) Safety Features and Requirements - It is a requirement that the H_2 reliquefaction system in no way degrade the structural or operational integrity of the existing LH_2 dewar. To assure that this requirement is met the system incorporates the following features:

- Structural beef-up of the dewar outer shell and guy wire supports that provide a large structural margin of safety.

- A closed loop refrigeration system that has no possibility of introducing any foreign material into the LH_2 dewar.

- A control and alarm system that initiates an automatic system shutdown, placing the system in a passive condition, and provides an alarm signal to operations personnel should any equipment failure occur. If this happens, the LH_2 dewar will continue to operate as if the H_2 reliquefaction system did not exist.

- Only the cold box is mounted on the LH_2 dewar. The rest of the H_2 reliquefaction equipment, primarily the compressors, are located on the ground.

- All electrical power wiring is located on the ground, the instrumentation and control wiring located on the dewar is minimal. The inherent simplicity of the system allows it to be controlled by only four single control elements. The power controllers which operate the compressors and the system control equipment are of the explosion proof type construction. In any instances where explosion proof construction is not feasible, N_2 purged enclosures will be used.

- System venting and overpressure relief valves are provided to relieve the system pressure should any overpressure condition arise.

- Air is prevented from entering the reliquefaction system by the vacuum insulated cold box and GH_2 pressurized jackets around all mechanical joints in the low pressure system. Thus, should any joint leakage occur, GH_2 will leak into the system as opposed to air.

- Gas conditioning units consisting of a deoxidizing unit, desiccant dryers, and activated charcoal filters are incorporated in the system plumbing to avoid system contamination.

  The purpose of the deoxidizing unit is to remove any oxygen from the system. This is accomplished by passing the hydrogen through a catalyst that combines any oxygen present with hydrogen to form water. The water is then removed by a desiccant dryer unit. The dryer is a dual unit, i.e., one side is on line while the other side is heated and purged.

- Activated charcoal filters are located downstream of the high temperature heat exchanger to remove any foreign gases such as nitrogen or CO_2 which may freeze in the system. This filter precludes line or valve plugging in the low temperature portion of the system.

2) Failure Modes and Effects Analysis - Virtually any failure will initiate an automatic system shutdown and place the H_2 reliquefaction system in a passive condition, but does not affect the normal operation of the LH_2 dewar. The automatic system shutdown mode shuts off the compressors and positions the valves as follows:

H_2 Inlet Valve	- Closed
Vent Valve	- Operating
Bypass Valve	- Open
J-T Valve	- Open at minimum setting
LN_2 Supply Valve	- Closed

With the system shut down, the hydrogen in the condenser will vaporize and vent through the vent valve until the system pressure stabilizes at 16 psia.

Specific failure modes and effects are discussed:

Failure Mode	Effect
Compressor Stops -Low oil pressure -High output temperatures -High oil temperature -High motor current -Power failure (compressor) Any of these conditions will shut down the compressor.	The pressure transducer upstream of J-T valve senses low pressure and initiates automatic system shutdown.
Control System power goes off.	H_2 inlet valve and vent valve will fail closed. Compressors shut off. Low pressure relief valve will vent as LH_2 boiloff increases pressure on low pressure side.
Lose LN_2 supply.	The temperature sensor in the LN_2 heat exchanger will sense a temperature rise and initiate automatic system shutdown.
Line Plugs	Pressure will become excessive and be sensed by the pressure transducer upstream of the J-T valve, which initiates automatic system shutdown.

Failure Mode	Effect
Condenser level sensor failure (continuous low level indication).	Redundant level sensors are provided to preclude such a failure. If both sensors fail, liquid will rise in condenser to a liquid sensor that initiates automatic shutdown.
Condenser level sensor fails (continuous high level indication) or bypass valve controller failure.	The bypass valve would go full open and reduce the pressure on the high pressure side of the system to such an extent that system operation would stop. Pressure transducer upstream of J-T valve would sense continued low pressure and initiate automatic system shutdown.
Operating vent valve fail closed, or valve controller failure.	System operation will be effected to the extent that the suction pressure to the compressor will be uncontrolled on the high end and the condenser temperature will increase due to the high pressure. If the pressure becomes excessive, the low pressure relief valve will open and vent the system. The pressure transducer will sense the high pressure and initiate automatic system shutdown.
Operating vent valve fail open (this is an abnormal failure since this valve is a fail closed type).	Pressure transducer senses low pressure and initiates automatic system shutdown.
J-T valve controller failure or failure of pressure transducer.	J-T valve closes to initial set point and system continues to operate but not necessarily at optimum efficiency.
GH_2 inlet valve controller failure.	This valve fails closed and system operation will continue with it closed except that the condenser pressure may be degraded sufficiently to cause the operating vent valve controller to give a low pressure automatic system shutdown signal.

Failure Mode	Effect
GH_2 inlet valve pressure transducer.	If the transducer fails with a continuous low pressure indication below 10 psia, the valve controller senses a low pressure condition and initiates automatic system shutdown.
Operating vent valve pressure transducer.	If the failure is a continuous low pressure signal, the valve controller will initiate automatic system shutdown. If the failure is a high pressure signal, the vent valve opens and reduces system pressure until the low pressure is sensed on the GH_2 inlet valve controller and initiates automatic system shutdown.
Relief valve failure.	If relief valve fails to open, a burst disc is provided to prevent system damage due to overpressure. Pressure transducers sense overpressure and initiate automatic system shutdown. Startup procedures would assure that relief valves are properly seated, that burst discs are replaced and that air is evacuated or purged from the system.
Loss of vacuum in the cold box due to external or internal leakage.	This condition would be recognized by a pressure switch located on the cold box which initiates automatic system shutdown.

X. CONCLUSIONS

Hydrogen reliquefaction of the boiloff from the dewars at LC-39 is economically feasible. All 132 combinations of system sizes, operational conditions, and cost escalation rates that were analyzed show substantial savings with relatively short pay-back periods. The maximum savings correspond to the largest size system. The cost estimates are based on performance data generated by the system analytical model. Features of this model include coupled heat transfer and fluid flow, a detailed submodel of the low-temperature heat exchanger, and real gas properties subroutines. The predicted yields, power requirements, and LN_2 requirements, therefore, should be close to actual values. Finally, there are many hydrogen liquefaction systems in operation at the present time, therefore, it has been shown that these systems are practical.

There are no technical or safety considerations precluding the incorporation of a hydrogen reliquefaction system on the dewars at LC-39. The dewar structure has been analyzed and shown to be capable of supporting the required equipment with only minor modification. A plan has been developed for penetrating the dewar that has essentially no thermal losses. The penetration can be made without degrading the dewar in any way. A conceptual control system has been developed that will deactivate the reliquefaction system in the event of equipment malfunction. Thus, the incorporation of a hydrogen reliquefaction system should in no way jeopardize the structural or operational integrity of the dewars.

An implementation plan has been developed that identified the major tasks required to incorporate the hydrogen reliquefaction system on LC-39B. Detailed equipment lists were made and equipment cost quotations were obtained from reputable suppliers. Total capital investment is estimated at $607,000, based on January 1978 rates. The system can be designed, tested, installed and checked out in a period of 14 months.

XI. RECOMMENDATIONS

The overall recommendation is to build a reliquefaction system. The minimum system size should be capable of liquefying all boiloff with one compressor operating and a second compressor added on stream for dewar loading and post launch operations. Hydrogen gas venting through the reliquefaction system is desirable during post launch and dewar loading time periods to increase the recovery rate.

The compressor should be of the nonlubricated type. Many manufacturers have indicated that this type of compressor will operate for more than 2000 hours between overhauls. Using this approach eliminates the requirement for oil separating equipment and will increase the overall reliability of the system. Also compressor maintenance scheduling should have little impact on the system long term performance if two compressors are used, as is being recommended. With a two-compressor system, the system operates during normal boiloff conditions on one compressor therefore, the other compressor can be overhauled with no impact on system performance.

A review of the design concepts at the National Bureau of Standards (NBS) at Boulder, Colorado revealed that improved system performance and lower condensing temperatures (and dewar pressure) may be achieved by incorporating an ejector in place of the Joule-Thomson valve. The ejector concept was developed at the NBS and has been used successfully in both nitrogen and helium cryogenic refrigeration systems. It is recommended that additional analysis be conducted to evaluate the merits of the ejector concept for possible incorporation into the hydrogen reliquefaction system.

APPENDIX A

Losses Incurred at Dewar Loading

APPENDIX A--LOSSES DUE TO DEWAR LOADING

The first law for loading the dewar with liquid hydrogen from the tanker trailers is given by the following equation:

[A-1] $hi\ \delta M = dU$ (assume no heat transfer loss to ambient)

where

hi = enthalpy of incoming liquid

δM = mass of incoming liquid during infinitesimal time step, $\Delta\tau$

U = total internal energy of hydrogen in the dewar = uM

u = specific internal of hydrogen in the dewar

M = mass of hydrogen in the dewar

Rewriting equation [A-1]:

[A-2] $hi\ \delta M = d(uM) = Mdu + udM$

The mass that enters the dewar is exactly the change of mass in the dewar.

Therefore

$\delta M = dM$

and,

[A-3] $hi\ dM = d(uM)$

If it is assumed that hi is a constant equation [A-3] can be integrated between the initial dewar state (1) and the final dewar state (2) to yield:

[A-4] $hi\ (M_2 - M_1) = u_2M_2 - u_1M_1$

[A-5] $h = u + pv$

$u = h - pv$

Substituting equation [A-5] into [A-4] yields

[A-6] $hi\ (M_2 - M_1) = M_2h_2 - p_2v_2M_2 - M_1h_1 + p_1v_1M_1$

[A-7] $$M_1 v_1 = M_2 v_2 = V$$

where

M = mass

v = specific volume

V = total volume of dewar

Combining equation [A-6] and [A-7] gives

[A-8] $$hi\ (M_2 - M_1) = M_2 h_2 - M_1 h_1 + V\ (P_1 - P_2)$$

Let y equal the volume fraction of liquid in the dewar; then mass of liquid in the dewar = $M_L = V \cdot y \cdot \rho_L$; where ρ_L = liquid density; mass of gas in the dewar = $M_g = V \cdot (1 - y)\ \rho_g$; where ρ_g = gas densit.

Quality (x) is defined as

[A-9] $$x = \frac{M_g}{M_L + M_g} = \frac{(1 - y)\ \rho_g}{y\rho_L + (1 - y)\ \rho_g}$$

Also

[A-10] $$h = h_L + x\left(h_g - h_L\right)$$

where

h_L = enthalpy of the liquid

h_g = enthalpy of the gas

h = total enthalpy

Combining equations [A-9] and [A-10] with [A-8] yield:

[A-11] $$hi\ (M_2 - M_1) = V\ (P_1 - P_2) + M_2 \left[h_L + \frac{(1 - y)\ \rho_g \left(h_g - h_L\right)}{y\rho_L\ (1 - y)\rho_g}\right]_2 - M_1 \left[h_L + \frac{(1 - y)\ \rho_g \left(h_g - h_L\right)}{y\rho_L + (1 - y)\ \rho_g}\right]_1$$

Also

[A-12] $$M_1 = V \left[y\rho_L + (1 - y)\ \rho_g \right]_1$$

[A-13] $$M_2 = V \left[y\rho_L + (1 - y)\ \rho_g \right]_2$$

With equations [A-11], [A-12], and [A-13] it is possible to determine the thermodynamic state of the dewar after a loading operation if the initial dewar pressure, the initial volume fraction of liquid hydrogen, and the inlet liquid hydrogen temperature is known. This is done by assuming a final liquid volume fraction and then repeatedly assuming final pressures, P_2, (P_2 establishes h_{L_2} and h_{g_2}) until equation [A-11] is balanced.

This calculation procedures was programmed on a Texas Instruments SR-52 calculator. For representative conditions of:

1) normal boiloff dewar state = 19 psia (saturated)

2) state of liquid from trailer = 21 psia (saturated)

3) initial dewar liquid volume = 20%

4) liquid loaded = 400,000 gal

the final pressure is 24.7 psia and the final liquid volume is 68%.

The next step in the analysis is to estimate the hydrogen losses in venting the tank from 24.7 psia to the normal boiloff condition of 19 psia. The first law for venting is given by:

[A-14] $$-ho\ \delta M = d\ (U) = d\ (uM)$$

ho = enthalpy of vented gas.

The mass that leaves the dewar is exactly equal to the change of mass in the dewar.

Therefore

$$\delta M = -dM$$

Also, the enthalpy of the vented gas changes only 2% over the extremes of the venting process; therefore, it can be assumed constant at the average value.

[A-15] $\bar{h}o\delta M = d(uM)$

$\bar{h}o$ = average vented gas enthalpy

This equation can be integrated just as equation [A-3] was handled. For the venting process, however, the end states are known. Therefore, the final volume fraction can be solved for directly. The equation for this quanity is as follows:

$$[A\text{-}16] \quad y_2 = \frac{\bar{h}o\left[\left(\rho_{g_1} - \rho_{g_2}\right) + y_1\left(\rho_{L_1} - \rho_{g_1}\right)\right] + \rho_{g_2} h_{g_2} - \rho_{g_1} h_{g_1} + y_1\left(\rho_{g_1} h_{g_1} - \rho_{L_1} h_{L_1}\right) - (P_2 - P_1)\frac{144}{778}}{\rho_{L_2}\left(\bar{h}o - h_{L_2}\right) + \rho_{g_2}\left(h_{g_2} - \bar{h}o\right)}$$

Also,

$$[A\text{-}17] \quad M_1 = V\left[y_1\,\rho_{L_1} + (1 - y_1)\,\rho_{g_1}\right]$$

$$[A\text{-}18] \quad M_2 = V\left[y_2\,\rho_{L_2} + (1 - y_2)\,\rho_{g_2}\right]$$

With y_2 determined from equation [A-16] and y_1 known, it is possible to find the loss by subtracting M_2 from M_1. For the case of dewar blowdown from 24.7 psia to 19 psia the loss is 8358 lbm, which equals approximately 14,380 gallons.

APPENDIX B
Life-Cycle Cost Computer Program Listing

```
DATE 03/24/77 TIME 10.30.31.  MARTIN MARIETTA THERMAL ANALYZER SYSTEM (MITAS II-FD363) CDC6000 SCOPE3.4 VERSION  PAGE    8
     TABLE     ------ LIFE CYCLE COST ------SYSTEM 1  NO VENTING          ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE
INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.        CARD NO.

              C-----------LIFE CYCLE COST DATA INPUT--------------------------------        A.   7          7
              C                                                                             A.   8          8
              C                                                                             A.   9          9
              C-------CAPITAL INVESTMENT COST, DOLLARS ------                               A.  10         10
                     2500= 178249.      $EQUIP AND MATERIAL (INCLUDES 1 COMPRESSORS)        A.  11         11
                     2501= 47134.0      $DETAILED DESIGN                                    A.  12         12
                     2502= 123940.      $FABRICATION                                        A.  13         13
                     2503= 51883.       $INSTALLATION                                       A.  14         14
                     2504= 1.000        $SYSTEM CAPITAL INVESTMENT MULTI. FACTOR            A.  15         15
              C                                                                             A.  16         16
              C-------OPERATING COST----------------------                                  A.  17         17
                     2510= 8.         $LABOR,HRS/WEEK                                       A.  18         18
                     2511= 12.        $LABOR RATE,DOLLARS/HOUR(CURRENT)                     A.  19         19
                     2512= 42.29*1.1  $POWER,KW --NORMAL BOILOFF                            A.  20         20
                     2513= 42.29*1.1  $POWER,KW --SHUTTLE LAUNCH                            A.  21         21
                     2514= 42.29*1.1  $POWER,KW --DEWAR LOADING                             A.  22         22
                     2515= .024       $POWER RATE,DOLLARS/KW-HR(CURRENT)                    A.  23         23
                     2516= 18.54*1.1  $LB/HR-LN2 --NORMAL BOILOFF                           A.  24         24
                     2517= 18.54*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                           A.  25         25
                     2518= 18.54*1.1  $LB/HR-LN2 --DEWAR LOADING                            A.  26         26
                     2519= .041       $LN2 RATE,DOLLARS/LB-LN2(CURRENT)                     A.  27         27
                     2520= 69.67      $WATER,GAL/HR--NORMAL BOILOFF                         A.  28         28
                     2521= 69.67      $WATER,GAL/HR--SHUTTLE LAUNCH                         A.  29         29
                     2522= 69.67      $WATER,GAL/HR--DEWAR LOADING                          A.  30         30
                     2523= .0003      $WATER RATE, DOLLARS/GAL (CURRENT)                    A.  31         31
              C                                                                             A.  32         32
              C-------MAINTENANCE COST---------------------                                 A.  33         33
                     2530= 6.9        $LABOR,HR/WEEK                                        A.  34         34
                     2531= 12.        $LABOR RATE,DOLLARS/HR (CURRENT)                      A.  35         35
                     2532= 500.       $MAINTENANCE MATERIALS,DOLLARS/YR                     A.  36         36
              C                                                                             A.  37         37
              C-------SAVINGS-----------------------------                                  A.  38         38
                     2540= 400.0      $H2 RELIQUEFACTION,GAL/DAY--NORMAL BOILOFF            A.  39         39
                     2541= 400.0      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH            A.  40         40
                     2542= 400.0      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING             A.  41         41
                     2543= 1.75       $COST OF LH2,DOLLARS/LB (CURRENT)                     A.  42         42
              C                                                                             A.  43         43
              C-------ESCALATION RATES --------------------                                 A.  44         44
                     2550= 6.         $OPERATING LABOR,PERCENT/YEAR                         A.  45         45
                     2551= 6.         $MAINTENANCE LABOR,PERCENT/YEAR                       A.  46         46
                     2552= 10.        $POWER,PERCENT/YEAR                                   A.  47         47
                     2553= 10.        $LN2,PERCENT/YEAR                                     A.  48         48
                     2554= 6.         $WATER,PERCENT/YEAR                                   A.  49         49
                     2555= 0.         $LH2,PERCENT/YEAR                                     A.  50         50
                     2556= 6.         $MAINTENANCE MATERIAL,PERCENT/YEAR                    A.  51         51
              C------OPERATIONAL PARAMETERS ---------------                                 A.  52         52
                     2560= 5.8        $PERCENT DOWN TIME FOR NORMAL BOILOFF MODE            A.  53         53
                     2561= 20.        $NUMBER OF SHUTTLE LAUNCHES PER YEAR                  A.  54         54
                     2562= 20.        $NUMBER OF DEWAR LOADINGS PER YEAR                    A.  55         55
                     2564= 48.        $HOURS ASSOCIATED WITH SHUTTLE LAUNCHES(EACH)         A.  56         56
                     2565= 24.*8.     $HOURS ASSOCIATED WITH DEWAR LOADING(EACH)            A.  57         57
                     2566= 15         $NUMBER OF YEARS OF SYSTEM LIFE                       A.  58         58
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TABLE     ------ LIFE CYCLE COST ------SYSTEM 1  NO VENTING          ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.        CARD NO.
          2570= 34.16     $LB/HR-H2 CIRCULATED--NORMAL BOILOFF                      A.   59       59
          2571= 34.16     $LB/HR-H2 CIRCULATED--SHUTTLE LAUNCH                      A.   60       60
          2572= 34.16     $LB/HR H2 CIRCULATED--DEWAR LOADING                       A.   61       61
          2573= 0.0       $ % H2 VENT RATE--NORMAL BOILOFF                          A.   62       62
          2574= 0.0       $ % H2 VENT RATE--SHUTTLE LAUNCH                          A.   63       63
          2575= 0.0       $ % H2 VENT RATE--DEWAR LOADING                           A.   64       64
          2576= 400.0     $GAL/DAY OF H2 LOSS NO SYSTEM--NORMAL BOILOFF             A.   65       65
          2577= 14450.    $GAL/LOAD OF H2 LOSS NO SYSTEM--SHUTTLE LAUNCH            A.   66       66
          2578= 14585.    $GAL/LOAD OF H2 LOSS NO SYSTEM--DEWAR LOADING             A.   67       67
      C                                                                             A.   68       68
      C------COMPUTED QUANTITIES ------------------                                 A.   69       69
          2600= 1.    $TOTAL CAPITAL INVESTMENT,DOLLARS                             A.   70       70
          2601= 1.    $OPER LABOR,DOLLAR/YEAR(CURRENT)                              A.   71       71
          2602= 1.    $H2-LIQUIFIED,LB/YEAR(NORMAL BOILOFF MODE)                    A.   72       72
          2603= 1.    $H2-LIQUIFIED,LB/YEAR(LAUNCH MODE)                            A.   73       73
          2604= 1.    $H2-LIQUIFIED,LB/YEAR(LOADING MODE)                           A.   74       74
          2605= 1.    $KW-HR/YEAR,(NORMAL BOILOFF MODE)                             A.   75       75
          2606= 1.    $KW-HR/YEAR,(LAUNCH MODE)                                     A.   76       76
          2607= 1.    $KW-HR/YEAR,(LOADING MODE)                                    A.   77       77
          2608= 1.    $TOTAL KW-HR/YEAR AND SUM OVER K YEARS                        A.   78       78
          2609= 1.    $COST OF POWER,DOLLARS/YEAR(CURRENT)                          A.   79       79
          2610= 1.    $N2 USE,LB/YEAR--NORMAL BOILOFF                               A.   80       80
          2611= 1.    $N2 USE,LB/YEAR--LAUNCH MODE                                  A.   81       81
          2612= 1.    $N2 USE,LB/YEAR--LOADING MODE                                 A.   82       82
          2613= 1.    $TOTAL N2 USE,LB/YEAR AND SUM OVER K YEARS                    A.   83       83
          2614= 1.    $COST OF N2,DOLLAR/YEAR(CURRENT)                              A.   84       84
          2615= 1.    $TOTAL WATER USE,GAL/YEAR                                     A.   85       85
          2616= 1.    $COST OF WATER,DOLLARS/YEAR(CURRENT)                          A.   86       86
          2617= 1.    $MAINTENANCE LABOR COST,DOLLARS/YEAR(CURRENT)                 A.   87       87
          2618= 1.    $MAINTENANCE MATL COST,DOLLARS/YEAR(CURRENT)                  A.   88       88
          2619= 1.    $TOTAL LB H2 LIQ/YEAR AND SUM OVER K YEARS                    A.   89       89
          2620= 1.    $TOTAL SAVINGS,DOLLARS/YEAR (CURRENT)                         A.   90       90
          2621= 1.    $LB/YEAR H2 LOSS NO SYSTEM                                    A.   91       91
          2622= 1.    $LB/YEAR H2 VENTED BY THE SYSTEM                              A.   92       92
          2700= 1.    $FIRST YEAR OPERATIONAL COST,DOLLARS                          A.   93       93
          2701= 1.    $FIRST YEAR MAINTENANCE COST,DOLLARS                          A.   94       94
          2702= 1.    $FIRST YEAR TOTAL COST,DOLLARS                                A.   95       95
          2703= 1.    $FIRST YEAR GROSS SAVINGS,DOLLARS                             A.   96       96
          2704= 1.    $FIRST YEAR NET SAVINGS,DOLLARS                               A.   97       97
          2710= 1.    $SUM OF OPERA. COST                                           A.   98       98
          2711= 1.    $SUM OF MAINT. COST                                           A.   99       99
          2712= 1.    $SUM OF TOTAL COST                                            A.  100      100
          2713= 1.    $SUM OF GROSS SAVINGS                                         A.  101      101
          2714= 1.    $SUM OF NET SAVINGS                                           A.  102      102
          2720= 1.    $YEARLY OPERA. COST                                           A.  103      103
          2721= 1.    $YEARLY MAINT. COST                                           A.  104      104
          2722= 1.    $YEARLY TOTAL COST                                            A.  105      105
          2723= 1.    $YEARLY GROSS SAVINGS                                         A.  106      106
          2724= 1.    $YEARLY NET SAVINGS                                           A.  107      107
          2801= 1.    $HOURS PER YEAR--NORMAL BOILOFF                               A.  108      108
          2802= 1.    $HOURS PER YEAR--SHUTTLE LAUNCH                               A.  109      109
          2803= 1.    $HOURS PER YEAR--DEWAR LOADING                                A.  110      110
```

```
TABLE     ------ LIFE CYCLE COST ------SYSTEM 1  NO VENTING          ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE
INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.        CARD NO.
                         2804= 1.    $H2 SAVED GAL/LOADING--SHUTTLE LAUNCH                          A.   111              111
                         2805= 1.    $H2 SAVED GAL/LOADING--DEWAR LOADING                           A.   112              112
                         END                                                                        A.   113              113

                                                 CONSTANTS DIRECTORY

                                                  INPUT=INTERNAL
 2500=   1 $  2501=   2 $  2502=   3 $  2503=   4 $  2504=   5 $  2510=   6 $  2511=   7 $  2512=   8 $  2513=   9
 2514=  10 $  2515=  11 $  2516=  12 $  2517=  13 $  2518=  14 $  2519=  15 $  2520=  16 $  2521=  17 $  2522=  18
 2523=  19 $  2530=  20 $  2531=  21 $  2532=  22 $  2540=  23 $  2541=  24 $  2542=  25 $  2543=  26 $  2550=  27
 2551=  28 $  2552=  29 $  2553=  30 $  2554=  31 $  2555=  32 $  2556=  33 $  2560=  34 $  2561=  35 $  2562=  36
 2564=  37 $  2565=  38 $  2566=  39 $  2570=  40 $  2571=  41 $  2572=  42 $  2573=  43 $  2574=  44 $  2575=  45
 2576=  46 $  2577=  47 $  2578=  48 $  2600=  49 $  2601=  50 $  2602=  51 $  2603=  52 $  2604=  53 $  2605=  54
 2606=  55 $  2607=  56 $  2608=  57 $  2609=  58 $  2610=  59 $  2611=  60 $  2612=  61 $  2613=  62 $  2614=  63
 2615=  64 $  2616=  65 $  2617=  66 $  2618=  67 $  2619=  68 $  2620=  69 $  2621=  70 $  2622=  71 $  2700=  72
 2701=  73 $  2702=  74 $  2703=  75 $  2704=  76 $  2710=  77 $  2711=  78 $  2712=  79 $  2713=  80 $  2714=  81
 2720=  82 $  2721=  83 $  2722=  84 $  2723=  85 $  2724=  86 $  2801=  87 $  2802=  88 $  2803=  89 $  2804=  90
 2805=  91 $
```

```
TABLE     ------ LIFE CYCLE COST ------SYSTEM 1  NO VENTING          ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.      CARD NO.

            BCD 3EXECUTION                                                            A.   114        114
      C-------LIFE CYCLE COST CALCULATIONS----------                                  A.   115        115
            R2600= R2500+R2501+R2502+R2503          $ TOTAL CAPITAL INVEST.           A.   116        116
            R2600= R2600*R2504                      $ TOT CAPITAL * MULI FAC.         A.   117        117
            R2601= R2510*R2511*52.  $OPER.LABOR,DOLLARS/YEAR(CURRENT)                 A.   118        118
            R2801= 365.*24.*(1.-R2560/100.)         $ HRS PER YEAR-NORMAL             A.   119        119
            R2802= R2561*R2564                      $ HRS PER YEAR-LAUNCH             A.   120        120
            R2803= R2562*R2565                      $ HRS PER YEAR-LOADING            A.   121        121
            R2602= R2540*R2801*.02451                 $LB LH2/YEAR-NORMAL             A.   122        122
            R2603= (R2541-R2540)*R2802*.02451         $LB LH2/YEAR-LAUNCH             A.   123        123
            R2604= (R2542-R2540)*R2803*.02451         $LB LH2/YEAR LOADING            A.   124        124
            R2605= R2512*(R2801-R2802-R2803) $KW-HR/YEAR --NORMAL BOILOFF             A.   125        125
            R2606= R2513*R2802               $KW-HR/YEAR --SHUTTLE LAUNCH             A.   126        126
            R2607= R2514*R2803               $KW-HR/YEAR --DEWAR LOADING              A.   127        127
            R2608= R2605+R2606+R2607  $TOTAL KW-HR/YEAR                               A.   128        128
            R2609= R2608*R2515    $COST OF POWER,DOLLARS/YEAR(CURRENT)                A.   129        129
            R2610= R2516*(R2801-R2802-R2803) $N2 USE,LB/YEAR--NORMAL BOILOFF          A.   130        130
            R2611= R2517*R2802               $N2 USE,LB/YEAR--SHUTTLE LAUNCH          A.   131        131
            R2612= R2518*R2803               $N2 USE,LB/YEAR--DEWAR LOADING           A.   132        132
            R2613= R2610+R2611+R2612 $TOTAL N2,LB/YEAR                                A.   133        133
            R2614= R2613*R2519    $COST OF N2,DOLLAR/YEAR(CURRENT)                    A.   134        134
            R2615= R2520*(R2801-R2802-R2803)      $ WATER--GAL/YR-NORMAL              A.   135        135
            R2615= R2615+R2521*R2802+R2522*R2803 $ WATER--GAL/YR                      A.   136        136
            R2616= R2615*R2523    $COST OF WATER,DOLLARS/YEAR(CURRENT)                A.   137        137
            R2617= R2530*R2531*52. $MAINTENANCE LABOR COST,DOLLARS/YEAR(CURR.)        A.   138        138
            R2618= R2532          $MAINTENANCE MATL COST,DOLLARS/YEAR(CURR.)          A.   139        139
            R2619= R2602+R2603+R2604 $TOTAL LB H2 LIQ/YEAR                            A.   140        140
            R2620= R2619*R2543    $TOTAL SAVINGS,DOLLARS/YEAR(CURRENT)                A.   141        141
            WRITE(6,500) H                                                            A.   142        142
      F500  FORMAT(1H1,/,10A6,/,10A6,/,)                                              A.   143        143
            WRITE(6,501)                                                              A.   144        144
      F501  FORMAT(9X,*CAPITAL INVESTMENT COST*9X*OPERATING COST*)                    A.   145        145
            WRITE(6,502)R2500,R2510                                                   A.   146        146
      F502  FORMAT(11X*EQUIP AND MATL= $*F11.2*    LABOR TIME=*F5.1* HR/WEEK          A.   147        147
      F    1 *)                                                                       A.   148        148
            WRITE(6,503)R2501,R2511                                                   A.   149        149
      F503  FORMAT(11X*DETAILED DESIGN=$*F11.2*    LABOR RATE=*F6.2* $/HR*)           A.   150        150
            WRITE(6,504)R2502,R2515                                                   A.   151        151
      F504  FORMAT(11X*FABRICATION    =$*F11.2*    POWER RATE=*F6.3* $/KW-HR          A.   152        152
      F    1 *)                                                                       A.   153        153
            WRITE(6,505)R2503,R2519                                                   A.   154        154
      F505  FORMAT(11X*INSTALLATION   =$*F11.2*    LN2 RATE   =*F6.3* $/LB*)          A.   155        155
            WRITE(6,507)R2523                                                         A.   156        156
      F507  FORMAT(28X*-----------    WATER RATE=*F6.4* $/GAL*)                       A.   157        157
            WRITE(6,508)R2504,R2600                                                   A.   158        158
      F508  FORMAT(11X,9HTOTAL * (,F4.2,*)  $*F11.2* */)                              A.   159        159
            WRITE(6,509)                                                              A.   160        160
      F509  FORMAT(9X*MAINTENANCE COST DATA*11X*SAVINGS DATA*)                        A.   161        161
            WRITE(6,510)R2530                                                         A.   162        162
      F510  FORMAT(11X*LABOR TIME=*F5.1* HR/WEEK*8X*HYDROGEN RELIQUEFIED*)            A.   163        163
            WRITE(6,511)R2531,R2540                                                   A.   164        164
      F511  FORMAT(11X*LABOR RATE=*F6.2* $/HR*11X*NORMAL BOILOFF =*F7.1* GAL/         A.   165        165
```

TABLE ------ LIFE CYCLE COST ------SYSTEM 1 NO VENTING ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

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INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.      CARD NO.
F      1DAY*)                                                                    A.   166       166
         R2804 =(R2541-R2540)*R2564/24.0     $ GAL/LOADING -SHUTTLE LAUNCH       A.   167       167
         WRITE(6,512)R2532,R2804                                                 A.   168       168
F512     FORMAT(11X*MATERIALS =*F8.2* $/YEAR*7X*SHUTTLE LAUNCH =*F7.1* GAL       A.   169       169
F      1/LOADING*)                                                               A.   170       170
         R2805 =(R2542-R2540)*R2565/24.0     $ GAL/LOADING -DEWAR LOADING        A.   171       171
         WRITE(6,513)R2805                                                       A.   172       172
F513     FORMAT(44X*DEWAR LOADING  =*F7.1* GAL/LOADING*)                         A.   173       173
         WRITE(6,514)R2619                                                       A.   174       174
F514     FORMAT(9X*ESCALATION RATES,PERCENT/YEAR*6X*TOTAL*9X*=*F10.1* LB/Y       A.   175       175
F      1EAR*)                                                                    A.   176       176
         WRITE(6,515)R2550,R2543                                                 A.   177       177
F515     FORMAT(11X*OPERATING LABOR=*F6.2,10X*LIQ HYDROGEN COST=*F6.2* $/L       A.   178       178
F      1B*)                                                                      A.   179       179
         WRITE(6,516)R2551                                                       A.   180       180
F516     FORMAT(11X*MAINTEN. LABOR =*F6.2* *)                                    A.   181       181
         WRITE(6,517)R2556                                                       A.   182       182
F517     FORMAT(11X*MAINTEN. MATL  =*F6.2,8X*OPERATIONAL PARAMETERS*)            A.   183       183
         WRITE(6,518)R2552,R2560                                                 A.   184       184
F518     FORMAT(11X*POWER*10X*=*F6.2,10X*PERCENT DOWN TIME*11X*=*F5.1*%*)        A.   185       185
         WRITE(6,519)R2553,R2561                                                 A.   186       186
F519     FORMAT(11X*LIQ NITROGEN   =*F6.2,10X*NO. OF SHUTTLE LAUNCHES/YEAR       A.   187       187
F      1=*F6.1)                                                                  A.   188       188
         WRITE(6,520)R2554,R2562                                                 A.   189       189
F520     FORMAT(11X*WATER*10X*=*F6.2,10X*NO. OF DEWAR LOADINGS/YR    =*          A.   190       190
F      1,F6.1)                                                                   A.   191       191
         WRITE(6,521)R2555                                                       A.   192       192
F521     FORMAT(11X*LIQ. HYDROGEN  =*F6.2/)                                      A.   193       193
         WRITE(6,522)                                                            A.   194       194
F522     FORMAT(9X*----------------------- CASH FLOW ------------------          A.   195       195
F      1--------------*)                                                         A.   196       196
         WRITE(6,523)R2600                                                       A.   197       197
F523     FORMAT(19X*TOTAL CAPITAL INVESTMENT COST = $*F11.2 /)                   A.   198       198
         WRITE(6,524)                                                            A.   199       199
F524     FORMAT(9X*YEAR OPERATING  MAINTENANCE  TOTAL COST  GROSS SAVINGS        A.   200       200
F      1 NET SAVINGS*)                                                           A.   201       201
         WRITE(6,525)                                                            A.   202       202
F525     FORMAT(16X*COST*8X*COST*/)                                              A.   203       203
         R2700=R2601+R2609+R2614+R2616  $TOTAL OPER COST,DOLLARS/YR-1            A.   204       204
         R2701=R2617+R2618              $TOTAL MAINTEN. COST,DOLLARS/YR-1        A.   205       205
         R2702=R2700+R2701+R2600        $TOTAL COST,DOLLAR/YEAR-1                A.   206       206
         R2703=R2620                    $GROSS SAVINGS,DOLLARS/YEAR-1            A.   207       207
         R2704=R2620 -R2702    $NET SAVINGS,DOLLAR/YEAR-1                        A.   208       208
         WRITE(6,526)R2700,R2701,R2702,R2703,R2704                               A.   209       209
F526     FORMAT(10X* 1 $*F9.1*  $*F9.1*  $*F9.1*  $*F10.1*   $*F10.1)            A.   210       210
         R2710=R2700                                                             A.   211       211
         R2711=R2701                                                             A.   212       212
         R2712=R2702                                                             A.   213       213
         R2713=R2703                                                             A.   214       214
         R2714=R2704                                                             A.   215       215
         ITOT =K2566                                                             A.   216       216
         DO 527 KK=2,ITOT                                                        A.   217       217
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TABLE     ------ LIFE CYCLE COST ------SYSTEM 1  NO VENTING          ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.       CARD NO.

              FAC = FLOAT(KK-1)                                                      A.   218          218
              R2720= R2601*(1.+R2550/100.)**FAC+R2609*(1.+R2552/100.)**FAC           A.   219          219
            1 +R2614*(1.+R2553/100.)**FAC+R2616*(1.+ R2554/100.)**FAC $ YR OP $      A.   220          220
              R2721=R2617*(1.+R2551/100.)**FAC                                       A.   221          221
            1 + R2618*(1.+R2556/100.)**FAC   $YEARLY MAINTEN.COST                    A.   222          222
              R2722=R2720+R2721                          $YEARLY TOTAL COST          A.   223          223
              R2723 = R2620*(1.+R2555/100.)**FAC $YEARLY GROSS SAVINGS               A.   224          224
              R2724 = R2723 - R2722                          $YEARLY NET SAVINGS     A.   225          225
              WRITE(6,528)KK,R2720,R2721,R2722,R2723,R2724                           A.   226          226
       F528   FORMAT(10X,I2,* $*F9.1*  $*F9.1*   $*F9.1*  $*F10.1*    $*F10.1)       A.   227          227
              R2710 = R2710 + R2720          $SUM OPERA.                             A.   228          228
              R2711 = R2711 + R2721          $SUM MAINTEN.                           A.   229          229
              R2712 = R2712 + R2722          $SUM TOTAL COST                         A.   230          230
              R2713 = R2713 + R2723          $SUM GROSS SAVINGS                      A.   231          231
              R2714 = R2714 + R2724          $SUM NET SAVINGS                        A.   232          232
              IF(R2714) 536,536,537                                                  A.   233          233
        536   KKP1 = KK                                                              A.   234          234
              KKP2 = KK + 1                                                          A.   235          235
        537   CONTINUE                                                               A.   236          236
        527   CONTINUE                                                               A.   237          237
              WRITE(6,529)                                                           A.   238          238
       F529   FORMAT(14X*----------   ----------   ----------   ----------     --    A.   239          239
       F    1--------*)                                                              A.   240          240
              WRITE(6,530)R2710,R2711,R2712,R2713,R2714                              A.   241          241
       F530   FORMAT(12X*$*F10.1* $*F10.1* $*F11.1* $*F11.1*   $*F11.1/)             A.   242          242
              R2714 = R2714/1.0E06                       $ SAVINGS IN MILLIONS       A.   243          243
              WRITE(6,531)KKP2,K2566,R2714                                           A.   244          244
       F531   FORMAT(16X*PAY BACK OCCURS DURING YEAR *I2,/                           A.   245          245
       F    1        16X*NET SAVINGS OVER *I2* YEARS =*F6.3* MILLION DOLLARS*/)      A.   246          246
              R2619 = R2619*(FLOAT(K2566))/1.0E06    $SUM H2 IN E06                  A.   247          247
              R2613 = R2613*(FLOAT(K2566))/1.0E06    $SUM N2 IN E06                  A.   248          248
              R2615 = R2615*(FLOAT(K2566))/1.0E06    $SUM H2O IN E06                 A.   249          249
              R2608 = R2608*(FLOAT(K2566))/1.0E06    $SUM POWER IN E06               A.   250          250
              R2621 = (R2576*365.0+R2577*R2561+R2578*R2562) $ LOSS GAL/YEAR          A.   251          251
              R2621 = R2621*(4.4/7.48)*FLOAT(K2566)/1.0E06  $ LOSS MIL LBS           A.   252          252
              R2622 = R2570*R2573*R2801+R2571*R2574*R2802+R2572*R2575*R2803          A.   253          253
              R2622 = R2622*FLOAT(K2566)/100./1.0E06        $ LBS VENTED MILL        A.   254          254
              WRITE(6,532)K2566,R2619,R2621,R2622                                    A.   255          255
       F532   FORMAT(16X*-------------- IN *I2* YEARS-------------------*,/          A.   256          256
       F    1        16X*TOTAL H2 SAVED WITH SYSTEM    =*F7.3* MILLION LBS*,/        A.   257          257
       F    1        16X*TOTAL H2 LOST WITH NO SYSTEM =*F7.3* MILLION LBS*,/         A.   258          258
       F    1        16X*TOTAL H2 VENTED BY SYSTEM     =*F7.3* MILLION LBS*)         A.   259          259
              WRITE(6,533)R2613,R2615                                                A.   260          260
       F533   FORMAT(16X*TOTAL NITROGEN EXPENDED       =*F7.3* MILLION LBS*,/        A.   261          261
       F    1        16X*TOTAL WATER EXPENDED          =*F7.3* MILLION GALS*)        A.   262          262
              WRITE(6,534)R2608                                                      A.   263          263
       F534   FORMAT(16X*TOTAL POWER EXPENDED          =*F7.3* MILLION KW-HR*)       A.   264          264
              WRITE(6,539)                                                           A.   265          265
              TOPLIN                                                                 A.   266          266
              PRINTA(1HR,R(1),NCON,1)                                                A.   267          267
       F539   FORMAT(1H1,///,20X,*END OF COST*)                                      A.   268          268
              END                                                                    A.   269          269
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TABLE      ------ LIFE CYCLE COST ------SYSTEM 1  NO VENTING          ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE
INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.        CARD NO.

                    BCD 3FINAL PARAMETERS                                                A.   270         270
                    BCD 3TITLE DATA                                                      A.   271         271
                    BCD 9 TABLE        ------ LIFE CYCLE COST ------SYSTEM 1  5% V       A.   272         272
                    BCD 9ENTING              ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 1       A.   273         273
                    BCD 25 YEAR LIFE                                                     A.   274         274
                    END                                                                  A.   275         275
                    BCD 3CONSTANTS DATA                                                  A.   276         276
                    2517= 13.57*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                         A.   277         277
                    2518= 13.58*1.1  $LB/HR-LN2 --DEWAR LOADING                          A.   278         278
                    2541= 480.9      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH          A.   279         279
                    2542= 486.6      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING           A.   280         280
                    2574= 5.0        $ % H2 VENT RATE--SHUTTLE LAUNCH                    A.   281         281
                    2575= 5.0        $ % H2 VENT RATE--DEWAR LOADING                     A.   282         282
                    END                                                                  A.   283         283
                    BCD 3FINAL PARAMETERS                                                A.   284         284
                    BCD 3TITLE DATA                                                      A.   285         285
                    BCD 9 TABLE        ------ LIFE CYCLE COST ------SYSTEM 1 10% V       A.   286         286
                    BCD 9ENTING              ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 1       A.   287         287
                    BCD 25 YEAR LIFE                                                     A.   288         288
                    END                                                                  A.   289         289
                    BCD 3CONSTANTS DATA                                                  A.   290         290
                    2517= 10.69*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                         A.   291         291
                    2518= 10.68*1.1  $LB/HR-LN2 --DEWAR LOADING                          A.   292         292
                    2541= 548.8      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH          A.   293         293
                    2542= 559.6      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING           A.   294         294
                    2574= 10.        $ % H2 VENT RATE--SHUTTLE LAUNCH                    A.   295         295
                    2575= 10.        $ % H2 VENT RATE--DEWAR LOADING                     A.   296         296
                    END                                                                  A.   297         297
                    BCD 3FINAL PARAMETERS                                                A.   298         298
                    BCD 3TITLE DATA                                                      A.   299         299
                    BCD 9 TABLE        ------ LIFE CYCLE COST ------SYSTEM 1 25% V       A.   300         300
                    BCD 9ENTING              ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 1       A.   301         301
                    BCD 25 YEAR LIFE                                                     A.   302         302
                    END                                                                  A.   303         303
                    BCD 3CONSTANTS DATA                                                  A.   304         304
                    2517=  7.00*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                         A.   305         305
                    2518=  6.88*1.1  $LB/HR-LN2 --DEWAR LOADING                          A.   306         306
                    2541= 727.4      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH          A.   307         307
                    2542= 746.2      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING           A.   308         308
                    2574= 25.        $ % H2 VENT RATE--SHUTTLE LAUNCH                    A.   309         309
                    2575= 25.        $ % H2 VENT RATE--DEWAR LOADING                     A.   310         310
                    END                                                                  A.   311         311
                    BCD 3FINAL PARAMETERS                                                A.   312         312
                    BCD 3TITLE DATA                                                      A.   313         313
                    BCD 9 TABLE        ------ LIFE CYCLE COST ------SYSTEM 1  NO V       A.   314         314
                    BCD 9ENTING              TWO COMPRESSORS, 20 LAUNCHES, 48 HRS        A.   315         315
                    BCD 215 YEAR LIFE                                                    A.   316         316
                    END                                                                  A.   317         317
                    BCD 3CONSTANTS DATA                                                  A.   318         318
                    2500= 275821.      $EQUIP AND MATERIAL (INCLUDES 2 COMPRESSORS)      A.   319         319
                    2513= 84.57*1.1  $POWER,KW --SHUTTLE LAUNCH                          A.   320         320
                    2514= 84.57*1.1  $POWER,KW --DEWAR LOADING                           A.   321         321
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     TABLE     ------ LIFE CYCLE COST ------SYSTEM 1  NO VENTING          TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.          CARD NO.

                  2517= 41.49*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                        A.   322          322
                  2518= 41.49*1.1  $LB/HR-LN2 --DEWAR LOADING                         A.   323          323
                  2521= 139.38     $WATER,GAL/HR--SHUTTLE LAUNCH                      A.   324          324
                  2522= 139.38     $WATER,GAL/HR--DEWAR LOADING                       A.   325          325
                  2541= 773.5      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH         A.   326          326
                  2542= 773.5      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING          A.   327          327
                  2560= 1.0        $PERCENT DOWN TIME FOR NORMAL BOILOFF MODE         A.   328          328
                  2570= 34.16      $LB/HR-H2 CIRCULATED--NORMAL BOILOFF               A.   329          329
                  2571= 68.31      $LB/HR-H2 CIRCULATED--SHUTTLE LAUNCH               A.   330          330
                  2572= 68.31      $LB/HR-H2 CIRCULATED--DEWAR LOADING                A.   331          331
                  2573= 0.0        $ % H2 VENT RATE--NORMAL BOILOFF                   A.   332          332
                  2574= 0.0        $ % H2 VENT RATE--SHUTTLE LAUNCH                   A.   333          333
                  2575= 0.0        $ % H2 VENT RATE--DEWAR LOADING                    A.   334          334
                  END                                                                 A.   335          335
                  BCD 3FINAL PARAMETERS                                               A.   336          336
                  BCD 3TITLE DATA                                                     A.   337          337
                  BCD 9 TABLE     ------ LIFE CYCLE COST ------SYSTEM 1  5% V         A.   338          338
                  BCD 9ENTING           TWO COMPRESSORS, 20 LAUNCHES, 48 HRS          A.   339          339
                  BCD 215 YEAR LIFE                                                   A.   340          340
                  END                                                                 A.   341          341
                  BCD 3CONSTANTS DATA                                                 A.   342          342
                  2517= 31.35*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                        A.   343          343
                  2518= 31.35*1.1  $LB/HR-LN2 --DEWAR LOADING                         A.   344          344
                  2541= 947.7      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH         A.   345          345
                  2542= 960.6      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING          A.   346          346
                  2574= 5.0        $ % H2 VENT RATE--SHUTTLE LAUNCH                   A.   347          347
                  2575= 5.0        $ % H2 VENT RATE--DEWAR LOADING                    A.   348          348
                  END                                                                 A.   349          349
                  BCD 3FINAL PARAMETERS                                               A.   350          350
                  BCD 3TITLE DATA                                                     A.   351          351
                  BCD 9 TABLE     ------ LIFE CYCLE COST ------SYSTEM 1 10% V         A.   352          352
                  BCD 9ENTING           TWO COMPRESSORS, 20 LAUNCHES, 48 HRS          A.   353          353
                  BCD 215 YEAR LIFE                                                   A.   354          354
                  END                                                                 A.   355          355
                  BCD 3CONSTANTS DATA                                                 A.   356          356
                  2517= 24.57*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                        A.   357          357
                  2518= 24.52*1.1  $LB/HR-LN2 --DEWAR LOADING                         A.   358          358
                  2541= 1091.      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH         A.   359          359
                  2542= 1113.      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING          A.   360          360
                  2574= 10.        $ % H2 VENT RATE--SHUTTLE LAUNCH                   A.   361          361
                  2575= 10.        $ % H2 VENT RATE--DEWAR LOADING                    A.   362          362
                  END                                                                 A.   363          363
                  BCD 3FINAL PARAMETERS                                               A.   364          364
                  BCD 3TITLE DATA                                                     A.   365          365
                  BCD 9 TABLE     ------ LIFE CYCLE COST ------SYSTEM 1 25% V         A.   366          366
                  BCD 9ENTING           TWO COMPRESSORS, 20 LAUNCHES, 48 HRS          A.   367          367
                  BCD 215 YEAR LIFE                                                   A.   368          368
                  END                                                                 A.   369          369
                  BCD 3CONSTANTS DATA                                                 A.   370          370
                  2517= 14.48*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                        A.   371          371
                  2518= 14.31*1.1  $LB/HR-LN2 --DEWAR LOADING                         A.   372          372
                  2541= 1461.      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH         A.   373          373
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TABLE     ------ LIFE CYCLE COST ------SYSTEM 1 25% VENTING          TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE
INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.        CARD NO.
                    2542= 1506.       $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING                A.  374          374
                    2574= 25.         $ % H2 VENT RATE--SHUTTLE LAUNCH                         A.  375          375
                    2575= 25.         $ % H2 VENT RATE--DEWAR LOADING                          A.  376          376
                    END                                                                        A.  377          377
                    BCD 3FINAL PARAMETERS                                                      A.  378          378
                    BCD 3TITLE DATA                                                            A.  379          379
                    BCD 9 TABLE      ------ LIFE CYCLE COST ------SYSTEM 2  NO V               A.  380          380
                    BCD 9ENTING           FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS                A.  381          381
                    BCD 215 YEAR LIFE                                                          A.  382          382
                    END                                                                        A.  383          383
                    BCD 3CONSTANTS DATA                                                        A.  384          384
                    2500= 470965.       $EQUIP AND MATERIAL (INCLUDES 2 COMPRESSORS)           A.  385          385
                    2513= 179.5*1.1   $POWER,KW --SHUTTLE LAUNCH                               A.  386          386
                    2514= 179.5*1.1   $POWER,KW --DEWAR LOADING                                A.  387          387
                    2517= 74.17*1.1   $LB/HR-LN2 --SHUTTLE LAUNCH                              A.  388          388
                    2518= 74.17*1.1   $LB/HR-LN2 --DEWAR LOADING                               A.  389          389
                    2521= 295.8       $WATER,GAL/HR--SHUTTLE LAUNCH                            A.  390          390
                    2522= 295.8       $WATER,GAL/HR--DEWAR LOADING                             A.  391          391
                    2541= 1748.0      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH               A.  392          392
                    2542= 1748.0      $H2 RELIQUEFACTION,GAL/DAY--DEWAR LOADING                A.  393          393
                    2560= 1.0         $PERCENT DOWN TIME FOR NORMAL BOILOFF MODE               A.  394          394
                    2570= 34.16       $LB/HR-H2 CIRCULATED--NORMAL BOILOFF                     A.  395          395
                    2571= 145.0       $LB/HR-H2 CIRCULATED--SHUTTLE LAUNCH                     A.  396          396
                    2572= 145.0       $LB/HR-H2 CIRCULATED--DEWAR LOADING                      A.  397          397
                    2573= 0.0         $ % H2 VENT RATE--NORMAL BOILOFF                         A.  398          398
                    2574= 0.0         $ % H2 VENT RATE--SHUTTLE LAUNCH                         A.  399          399
                    2575= 0.0         $ % H2 VENT RATE--DEWAR LOADING                          A.  400          400
                    END                                                                        A.  401          401
                    BCD 3FINAL PARAMETERS                                                      A.  402          402
                    BCD 3TITLE DATA                                                            A.  403          403
                    BCD 9 TABLE      ------ LIFE CYCLE COST ------SYSTEM 2  5% V               A.  404          404
                    BCD 9ENTING           FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS                A.  405          405
                    BCD 215 YEAR LIFE                                                          A.  406          406
                    END                                                                        A.  407          407
                    BCD 3CONSTANTS DATA                                                        A.  408          408
                    2517= 53.20*1.1   $LB/HR-LN2 --SHUTTLE LAUNCH                              A.  409          409
                    2541= 2063.       $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH               A.  410          410
                    2574= 5.0         $ % H2 VENT RATE--SHUTTLE LAUNCH                         A.  411          411
                    END                                                                        A.  412          412
                    BCD 3FINAL PARAMETERS                                                      A.  413          413
                    BCD 3TITLE DATA                                                            A.  414          414
                    BCD 9 TABLE      ------ LIFE CYCLE COST ------SYSTEM 2 10% V               A.  415          415
                    BCD 9ENTING           FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS                A.  416          416
                    BCD 215 YEAR LIFE                                                          A.  417          417
                    END                                                                        A.  418          418
                    BCD 3CONSTANTS DATA                                                        A.  419          419
                    2517= 42.16*1.1   $LB/HR-LN2 --SHUTTLE LAUNCH                              A.  420          420
                    2541= 2342.       $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH               A.  421          421
                    2574= 10.         $ % H2 VENT RATE--SHUTTLE LAUNCH                         A.  422          422
                    END                                                                        A.  423          423
                    BCD 3FINAL PARAMETERS                                                      A.  424          424
                    BCD 3TITLE DATA                                                            A.  425          425
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INPUT CARD COL. = 12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 2345678 8 EDIT NO.        CARD NO.
                  BCD 9 TABLE     ------ LIFE CYCLE COST ------SYSTEM 2 25% V                     A.   426              426
                  BCD 9ENTING          FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS                      A.   427              427
                  BCD 215 YEAR LIFE                                                               A.   428              428
                  END                                                                             A.   429              429
                  BCD 3CONSTANTS DATA                                                             A.   430              430
                  2517= 28.68*1.1  $LB/HR-LN2 --SHUTTLE LAUNCH                                    A.   431              431
                  2541= 3087.      $H2 RELIQUEFACTION,GAL/DAY--SHUTTLE LAUNCH                     A.   432              432
                  2574= 25.        $ % H2 VENT RATE--SHUTTLE LAUNCH                               A.   433              433
                  END                                                                             A.   434              434
                  BCD 3END OF DATA                                                                A.   435              435
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APPENDIX C
System Performance Computer Program Listing

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NOT RESTART
        NGENL = NG
        BCD 3TITLE DATA
        BCD 9 H2 RELIQ. THERMAL MODEL NOMINAL BOILOFF CASE
        BCD 9 DIVERTER VALVE AT 95%  FLOW THRU HX2
        END
C*********************************************************************
        BCD 3NODE DATA
        405, 300., -1.            $ COMPRESSOR L.P. INLET
        410, 300., -1.            $ HIGE PRESS HX INLET DIVERTER VALVE
        415, 300., -1.            $ HX2 INLET H.P. SIDE
        420, 120., -1.            $ HX2 OUTLET H.P. SIDE
        425, 300., -1.            $ HX3 INLET H.P. SIDE
        430, 120., -1.            $ HX3 OUTLET H.P. SIDE
        435, 120., -1.            $ HX1 / HX2 MIXING VALVE
        440,  90., -1.            $ GH2 LN2 HX OUTLET
        442,  30., -1.            $ INLET TO JT VALVE
        500,  85., -1.            $ HX1 HIGH PRESS. INLET
        GEN 501, 50, 1,  80.0, -1.         $ HX1 HIGH PRESS. NODES
        599,        70.0, -1.              $ HX1 HIGH PRESS OUTLET
        600,      30.0,  -1.               $ HX1 LOW PRESS. INLET
        GEN 650, 25, -2,  30.0, -1.        $ HX1 LOW PRESS. GAS NODES
        GEN 649, 25, -2,  30.0, -1.        $ HX1 LOW PRESS. GAS NODES
        699,        80.0, -1.              $ HX1 LOW PRESS GAS OUTLET
        GEN 701, 10, 1,  80.0, -1.         $ HX1 HX WALL NODES
        445,  30., -1.             $ SEPERATOR
        450,  80., -1.             $ HX2 INLET L.P. SIDE
        455, 300., -1.             $ HX2 OUTLET L.P. SIDE
        460, 300., -1.             $ GH2 LINE VENT
        465,  80., -1.             $ HX3 GN2 INLET L.P. SIDE
        470, 300., -1.             $ HX3 GN2 OUTLET L.P. SIDE
        1000,  77.0, -1.           $ COLD BOX INNER MLI LAYER
        1500, 300.0, -1.           $ COLD BOX OUTER SKIN
        -305.     300.,  0.       $ COMPRESSOR OUTLET TEMP DEG K
        -309.     21.67, 0.       $ DEWAR ULLAGE TEMP DEG K FOR LOADING
        -310.      20.,  0.       $ OUTLET TEMP AT JT VALVE DEG K
        -320.      77.,  0.       $ LN2 SUPPLY TEMP
        -9999,   300.0, 0.         $ AMBIENT DEG K
C
C   CYCLE PRESSURE NODES CALCULATED IN V2 (ATMOSPHERES)
C
        -1305, 80.0, 0.              $ COMPRESSOR OUTLET
        -1309, 1.50, 0.              $ DEWAR ULLAGE PRES. FOR LOADING
        -1310, 1.05, 0.              $ L.P. CLOSED LOOP OUT OF JT VALVE
        -1405, 1.05, 0.              $ L.P. INLET TO COMP.
        -1410, 80.0, 0.              $ H.P. INLET TO HX2/HX3
        -1435, 80.0, 0.              $ H.P. MIXING VALVE OUTLET
        -1440, 80.0, 0.              $ H.P. OUTLET OF LN2 BATH
        -1442, 80.0, 0.              $ H.P. INLET TO JT VALVE
        -1445, 1.05, 0.              $ L.P. SEPERATOR
        -1450, 1.05, 0.              $ L.P. INLET TO HX2
        -1460, 1.05, 0.              $ L.P. AT VENT VALVE
        -1600, 1.05, 0.              $ L.P. INLET TO HX1
        -1699, 1.05, 0.              $ L.P. OUTLET TO HX1
        END
C*********************************************************************
        BCD 3CONDUCTOR DATA
C*********************************************************************
C
C   SYSTEM ONE WAY FLOW CONDUCTORS (VALUES CALCULATED IN V1)
C
        30510, -305, 410, 1.         $ H.P. COMP. OUTLET TO DIVERTER VALVE
        41015, -410, 415, 1.         $ H.P. DIVERTER VALVE TO HX2 INLET
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        41520, -415, 420, 1.         $ H.P. HX2 INLET TO OUTLET
        42035, -420, 435, 1.         $ H.P. HX2 OUTLET TO MIXING VALVE
        41025, -410, 425, 1.         $ H.P. DIVERTER TO HX3 INLET
        42530, -425, 430, 1.         $ H.P. HX3 INLET TO OUTLET
        43035, -430, 435, 1.         $ H.P. HX3 OUTLET TO MIXING VALVE
        43540, -435, 440, 1.         $ H.P. MIXING VALVE TO LN2 BATH OUTLET
        44050, -440, 500, 1.         $ H.P. LN2 OUTLET TO HX1 INLET
        49942, -599, 442, 1.         $ H.P. HX1 OUTLET TO JT VALVE INLET
        31045, -310, 445, 1.         $ L.P. JT OUTLET TO SEPERATOR
        30945, -309, 445, 1.         $ DEWAR VENT TO SEPERATOR
        44560, -445, 600, 1.         $ L.P. SEPERATOR TO HX1 INLET
        49950, -699, 450, 1.         $ L.P. HX1 OUTLET TO HX2 INLET
        45055, -450, 455, 1.         $ L.P. HX2 INLET TO OUTLET
        45560, -455, 460, 1.         $ L.P. HX2 OUTLET TO VENT
        46005, -460, 405, 1.         $ L.P. VENT TO COMP. INLET
        32065, -320, 465, 1.         $ LN2 BOILOFF TO HX3 L.P.INLET
        46570, -465, 470, 1.         $ L.P. HX3 INLET TO OUTLET
C
C       HX CROSS OVER FLOW COND,S.
C
        42570, -425, 470, 1.         $ H.P. HX3 INLET TO L.P. OUTLET
        46530, -465, 430, 1.         $ L.P. HX3 INLET TO H.P. OUTLET
        41555, -415, 455, 1.         $ H.P. HX2 INLET TO L.P. OUTLET
        45020, -450, 420, 1.         $ L.P. HX2 INLET TO H.P. OUTLET
C
C       SYSTEM LINE CIONVECTION COND.S.
C
        1001, 320, 440, 300.         $ H.P. GH2 IN COIL TO LN2 BATH V1
C
C     LOW TEMPERATURE HEAT EXCHANGER (HX1) CONDUCTOR NETWORK
C
      CGS 551, -500, 501, A21, R1011  $ H.P.MDOTXCP INLET
      CGS 552, -500, 511, A21, R1012  $ H.P.MDOTXCP INLET
      CGS 553, -500, 521, A21, R1013  $ H.P.MDOTXCP INLET
      CGS 554, -500, 531, A21, R1014  $ H.P.MDOTXCP INLET
      CGS 555, -500, 541, A21, R1015  $ H.P.MDOTXCP INLET
C       HIGH PRESSURE MDOT * CP GAS TUBE NODES LOOP 1
      CGS 501, -501, 502, A21, R1011  $ H.P.MDOTXCP
      CGS 502, -502, 503, A21, R1011  $ H.P.MDOTXCP
      CGS 503, -503, 504, A21, R1011  $ H.P.MDOTXCP
      CGS 504, -504, 505, A21, R1011  $ H.P.MDOTXCP
      CGS 505, -505, 506, A21, R1011  $ H.P.MDOTXCP
      CGS 506, -506, 507, A21, R1011  $ H.P.MDOTXCP
      CGS 507, -507, 508, A21, R1011  $ H.P.MDOTXCP
      CGS 508, -508, 509, A21, R1011  $ H.P.MDOTXCP
      CGS 509, -509, 510, A21, R1011  $ H.P.MDOTXCP
      CGS 510, -510, 599, A21, R1011  $ H.P.MDOTXCP OUTLET
C       HIGH PRESSURE MDOT * CP GAS TUBE NODES LOOP 2
      CGS 511, -511, 512, A21, R1012  $ H.P.MDOTXCP
      CGS 512, -512, 513, A21, R1012  $ H.P.MDOTXCP
      CGS 513, -513, 514, A21, R1012  $ H.P.MDOTXCP
      CGS 514, -514, 515, A21, R1012  $ H.P.MDOTXCP
      CGS 515, -515, 516, A21, R1012  $ H.P.MDOTXCP
      CGS 516, -516, 517, A21, R1012  $ H.P.MDOTXCP
      CGS 517, -517, 518, A21, R1012  $ H.P.MDOTXCP
      CGS 518, -518, 519, A21, R1012  $ H.P.MDOTXCP
      CGS 519, -519, 520, A21, R1012  $ H.P.MDOTXCP
      CGS 520, -520, 599, A21, R1012  $ H.P.MDOTXCP OUTLET
C       HIGH PRESSURE MDOT * CP GAS TUBE NODES LOOP 3
      CGS 521, -521, 522, A21, R1013  $ H.P.MDOTXCP
      CGS 522, -522, 523, A21, R1013  $ H.P.MDOTXCP
      CGS 523, -523, 524, A21, R1013  $ H.P.MDOTXCP
      CGS 524, -524, 525, A21, R1013  $ H.P.MDOTXCP
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      CGS 525, -525, 526, A21, R1013  $ H.P.MDOTXCP
      CGS 526, -526, 527, A21, R1013  $ H.P.MDOTXCP
      CGS 527, -527, 528, A21, R1013  $ H.P.MDOTXCP
      CGS 528, -528, 529, A21, R1013  $ H.P.MDOTXCP
      CGS 529, -529, 530, A21, R1013  $ H.P.MDOTXCP
      CGS 530, -530, 599, A21, R1013  $ H.P.MDOTXCP OUTLET
C       HIGH PRESSURE MDOT * CP GAS TUBE NODES LOOP 4
      CGS 531, -531, 532, A21, R1014  $ H.P.MDOTXCP
      CGS 532, -532, 533, A21, R1014  $ H.P.MDOTXCP
      CGS 533, -533, 534, A21, R1014  $ H.P.MDOTXCP
      CGS 534, -534, 535, A21, R1014  $ H.P.MDOTXCP
      CGS 535, -535, 536, A21, R1014  $ H.P.MDOTXCP
      CGS 536, -536, 537, A21, R1014  $ H.P.MDOTXCP
      CGS 537, -537, 538, A21, R1014  $ H.P.MDOTXCP
      CGS 538, -538, 539, A21, R1014  $ H.P.MDOTXCP
      CGS 539, -539, 540, A21, R1014  $ H.P.MDOTXCP
      CGS 540, -540, 599, A21, R1014  $ H.P.MDOTXCP OUTLET
C       HIGH PRESSURE MDOT * CP GAS TUBE NODES LOOP 5
      CGS 541, -541, 542, A21, R1015  $ H.P.MDOTXCP
      CGS 542, -542, 543, A21, R1015  $ H.P.MDOTXCP
      CGS 543, -543, 544, A21, R1015  $ H.P.MDOTXCP
      CGS 544, -544, 545, A21, R1015  $ H.P.MDOTXCP
      CGS 545, -545, 546, A21, R1015  $ H.P.MDOTXCP
      CGS 546, -546, 547, A21, R1015  $ H.P.MDOTXCP
      CGS 547, -547, 548, A21, R1015  $ H.P.MDOTXCP
      CGS 548, -548, 549, A21, R1015  $ H.P.MDOTXCP
      CGS 549, -549, 550, A21, R1015  $ H.P.MDOTXCP
      CGS 550, -550, 599, A21, R1015  $ H.P.MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME INLETS
      CGS 661, -600, 650, A22, R1020  $ L.P. MDOTXCP
      CGS 662, -600, 640, A22, R1020  $ L.P. MDOTXCP
      CGS 663, -600, 630, A22, R1020  $ L.P. MDOTXCP
      CGS 664, -600, 620, A22, R1020  $ L.P. MDOTXCP
      CGS 665, -600, 610, A22, R1020  $ L.P. MDOTXCP
      CGS 666, -600, 649, A22, R1020  $ L.P. MDOTXCP
      CGS 667, -600, 639, A22, R1020  $ L.P. MDOTXCP
      CGS 668, -600, 629, A22, R1020  $ L.P. MDOTXCP
      CGS 669, -600, 619, A22, R1020  $ L.P. MDOTXCP
      CGS 670, -600, 609, A22, R1020  $ L.P. MDOTXCP
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 5B
      CGS 601, -650, 648, A22, R1020  $ L.P. MDOTXCP
      CGS 602, -648, 646, A22, R1020  $ L.P. MDOTXCP
      CGS 603, -646, 644, A22, R1020  $ L.P. MDOTXCP
      CGS 604, -644, 642, A22, R1020  $ L.P. MDOTXCP
      CGS 605, -642, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 4B
      CGS 606, -640, 638, A22, R1020  $ L.P. MDOTXCP
      CGS 607, -638, 636, A22, R1020  $ L.P. MDOTXCP
      CGS 608, -636, 634, A22, R1020  $ L.P. MDOTXCP
      CGS 609, -634, 632, A22, R1020  $ L.P. MDOTXCP
      CGS 610, -632, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 3B
      CGS 611, -630, 628, A22, R1020  $ L.P. MDOTXCP
      CGS 612, -628, 626, A22, R1020  $ L.P. MDOTXCP
      CGS 613, -626, 624, A22, R1020  $ L.P. MDOTXCP
      CGS 614, -624, 622, A22, R1020  $ L.P. MDOTXCP
      CGS 615, -622, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 2B
      CGS 616, -620, 618, A22, R1020  $ L.P. MDOTXCP
      CGS 617, -618, 616, A22, R1020  $ L.P. MDOTXCP
      CGS 618, -616, 614, A22, R1020  $ L.P. MDOTXCP
      CGS 619, -614, 612, A22, R1020  $ L.P. MDOTXCP
      CGS 620, -612, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 1B
      CGS 621, -610, 608, A22, R1020  $ L.P. MDOTXCP
      CGS 622, -608, 606, A22, R1020  $ L.P. MDOTXCP
      CGS 623, -606, 604, A22, R1020  $ L.P. MDOTXCP
      CGS 624, -604, 602, A22, R1020  $ L.P. MDOTXCP
      CGS 625, -602, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 5A
      CGS 626, -649, 647, A22, R1020  $ L.P. MDOTXCP
      CGS 627, -647, 645, A22, R1020  $ L.P. MDOTXCP
      CGS 628, -645, 643, A22, R1020  $ L.P. MDOTXCP
      CGS 629, -643, 641, A22, R1020  $ L.P. MDOTXCP
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 4A
      CGS 630, -641, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
      CGS 631, -639, 637, A22, R1020  $ L.P. MDOTXCP
      CGS 632, -637, 635, A22, R1020  $ L.P. MDOTXCP
      CGS 633, -635, 633, A22, R1020  $ L.P. MDOTXCP
      CGS 634, -633, 631, A22, R1020  $ L.P. MDOTXCP
      CGS 635, -631, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 3A
      CGS 636, -629, 627, A22, R1020  $ L.P. MDOTXCP
      CGS 637, -627, 625, A22, R1020  $ L.P. MDOTXCP
      CGS 638, -625, 623, A22, R1020  $ L.P. MDOTXCP
      CGS 639, -623, 621, A22, R1020  $ L.P. MDOTXCP
      CGS 640, -621, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 2A
      CGS 641, -619, 617, A22, R1020  $ L.P. MDOTXCP
      CGS 642, -617, 615, A22, R1020  $ L.P. MDOTXCP
      CGS 643, -615, 613, A22, R1020  $ L.P. MDOTXCP
      CGS 644, -613, 611, A22, R1020  $ L.P. MDOTXCP
      CGS 645, -611, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       LOW PRESSURE MDOT * CP GAS VOLUME NODES LOOP 1A
      CGS 646, -609, 607, A22, R1020  $ L.P. MDOTXCP
      CGS 647, -607, 605, A22, R1020  $ L.P. MDOTXCP
      CGS 648, -605, 603, A22, R1020  $ L.P. MDOTXCP
      CGS 649, -603, 601, A22, R1020  $ L.P. MDOTXCP
      CGS 650, -601, 699, A22, R1020  $ L.P. MDOTXCP OUTLET
C       H*A CONVECTION H.P. GAS IN TUBES TO GAS VOLUMES LOOP1
          CGS   701,   501, 601, A23, R1031 $ HA H.P. TO L.P.
                702,   502, 602, 1. $ R1031   HA H.P. TO L.P.
          CGS   703,   503, 603, A23, R1031 $ HA H.P. TO L.P.
                704,   504, 604, 1. $ R1031   HA H.P. TO L.P.
          CGS   705,   505, 605, A23, R1031 $ HA H.P. TO L.P.
                706,   506, 606, 1. $ R1031   HA H.P. TO L.P.
          CGS   707,   507, 607, A23, R1031 $ HA H.P. TO L.P.
                708,   508, 608, 1. $ R1031   HA H.P. TO L.P.
          CGS   709,   509, 609, A23, R1031 $ HA H.P. TO L.P.
                710,   510, 610, 1. $ R1031   HA H.P. TO L.P.
C       H*A CONVECTION H.P. GAS IN TUBES TO GAS VOLUMES LOOP2
          CGS   711,   511, 611, A23, R1032 $ HA H.P. TO L.P.
                712,   512, 612, 1. $ R1032   HA H.P. TO L.P.
          CGS   713,   513, 613, A23, R1032 $ HA H.P. TO L.P.
                714,   514, 614, 1. $ R1032   HA H.P. TO L.P.
          CGS   715,   515, 615, A23, R1032 $ HA H.P. TO L.P.
                716,   516, 616, 1. $ R1032   HA H.P. TO L.P.
          CGS   717,   517, 617, A23, R1032 $ HA H.P. TO L.P.
                718,   518, 618, 1. $ R1032   HA H.P. TO L.P.
          CGS   719,   519, 619, A23, R1032 $ HA H.P. TO L.P.
                720,   520, 620, 1. $ R1032   HA H.P. TO L.P.
C       H*A CONVECTION H.P. GAS IN TUBES TO GAS VOLUMES LOOP3
          CGS   721,   521, 621, A23, R1033 $ HA H.P. TO L.P.
                722,   522, 622, 1. $ R1033   HA H.P. TQ L.P.
          CGS   723,   523, 623, A23, R1033 $ HA H.P. TO L.P.
                724,   524, 624, 1. $ R1033   HA H.P. TO L.P.
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      CGS  725,   525, 625, A23, R1033 $ HA H.P. TO L.P.
           726,   526, 626, 1. $ R1033   HA H.P. TO L.P.
      CGS  727,   527, 627, A23, R1033 $ HA H.P. TO L.P.
           728,   528, 628, 1. $ R1033   HA H.P. TO L.P.
      CGS  729,   529, 629, A23, R1033 $ HA H.P. TO L.P.
           730,   530, 630, 1. $ R1033   HA H.P. TO L.P.
C     H*A CONVECTION H.P. GAS IN TUBES TO GAS VOLUMES LOOP4
      CGS  731,   531, 631, A23, R1034 $ HA H.P. TO L.P.
           732,   532, 632, 1. $ R1034   HA H.P. TO L.P.
      CGS  733,   533, 633, A23, R1034 $ HA H.P. TO L.P.
           734,   534, 634, 1. $ R1034   HA H.P. TO L.P.
      CGS  735,   535, 635, A23, R1034 $ HA H.P. TO L.P.
           736,   536, 636, 1. $ R1034   HA H.P. TO L.P.
      CGS  737,   537, 637, A23, R1034 $ HA H.P. TO L.P.
           738,   538, 638, 1. $ R1034   HA H.P. TO L.P.
      CGS  739,   539, 639, A23, R1034 $ HA H.P. TO L.P.
           740,   540, 640, 1. $ R1034   HA H.P. TO L.P.
C     H*A CONVECTION H.P. GAS IN TUBES TO GAS VOLUMES LOOP5
      CGS  741,   541, 641, A23, R1035 $ HA H.P. TO L.P.
           742,   542, 642, 1. $ R1035   HA H.P. TO L.P.
      CGS  743,   543, 643, A23, R1035 $ HA H.P. TO L.P.
           744,   544, 644, 1. $ R1035   HA H.P. TO L.P.
      CGS  745,   545, 645, A23, R1035 $ HA H.P. TO L.P.
           746,   546, 646, 1. $ R1035   HA H.P. TO L.P.
      CGS  747,   547, 647, A23, R1035 $ HA H.P. TO L.P.
           748,   548, 648, 1. $ R1035   HA H.P. TO L.P.
      CGS  749,   549, 649, A23, R1035 $ HA H.P. TO L.P.
           750,   550, 650, 1. $ R1035   HA H.P. TO L.P.
C     H*A GAS VOLUMES TO INNER CYLINDER WALL
      CGS 751, 701, 601, A23, R1040   $ L.P. GAS HA TO INNER CYL
          752, 701, 602, 1. $ R1040     L.P. GAS HA TO INNER CYL
      CGS 753, 702, 603, A23, R1040   $ L.P. GAS HA TO INNER CYL
          754, 702, 604, 1. $ R1040     L.P. GAS HA TO INNER CYL
      CGS 755, 703, 605, A23, R1040   $ L.P. GAS HA TO INNER CYL
          756, 703, 606, 1. $ R1040     L.P. GAS HA TO INNER CYL
      CGS 757, 704, 607, A23, R1040   $ L.P. GAS HA TO INNER CYL
          758, 704, 608, 1. $ R1040     L.P. GAS HA TO INNER CYL
      CGS 759, 705, 609, A23, R1040   $ L.P. GAS HA TO INNER CYL
          760, 705, 610, 1. $ R1040     L.P. GAS HA TO INNER CYL
      CGS 761, 706, 641, A23, R1050   $ L.P. GAS HA TO OUTTER CYL
          762, 706, 642, 1. $ R1050     L.P. GAS HA TO OUTTER CYL
      CGS 763, 707, 643, A23, R1050   $ L.P. GAS HA TO OUTTER CYL
          764, 707, 644, 1. $ R1050     L.P. GAS HA TO OUTTER CYL
      CGS 765, 708, 645, A23, R1050   $ L.P. GAS HA TO OUTTER CYL
          766, 708, 646, 1. $ R1050     L.P. GAS HA TO OUTTER CYL
      CGS 767, 709, 647, A23, R1050   $ L.P. GAS HA TO OUTTER CYL
          768, 709, 648, 1. $ R1050     L.P. GAS HA TO OUTTER CYL
      CGS 769, 710, 649, A23, R1050   $ L.P. GAS HA TO OUTTER CYL
          770, 710, 650, 1. $ R1050     L.P. GAS HA TO OUTTER CYL
C
C     RADIATION HEAT LEAK CONDUCTORS
C
         -771, 701, 1000, 702, 1000, 703, 1000, 704, 1000
               705, 1000, 0.               $ HX1 INNER CYL TO MLI..
         -772, 706, 1000, 707, 1000, 708, 1000, 709, 1000
               710, 1000, 0.               $ HX1 OUTER CYL TO MLI
         -775, 435, 1000, 0.               $ HIGH TEMP HX2/HX3 TO MLI
         -780, 320, 1000, 0.               $ LN2 BATH TO MLI
         -785, 145, 1000, 0.               $ CONDENSOR TO MLI
         -790, 1000, 1500, 0.              $ MLI TO TANK WALL EFF. E
          800, 1500, 9999, 0.              $ COLD BOX CONV. TO AMB
      END
C*******************************************************************
```

```
      BCD 3CONSTANTS DATA
C*******************************************************************
C
C     NETWORK SOLUTION PARAMETERS
C
      NDSTOR = 1000, ARLXCA = 1.00, EBALSA = 1.0, EBALNA = 1.0
      ITERMX = 26, ITEROT = 25, EBALSC=1.0E06, EBALNC=1.0E06
C
         1 = 106.0    $ **INPUT** VOL. FLOW RATE OF COMPRESSOR SCFM
      1001 = 3.1413        $ PIE USED IN SUBROUTINE HXFLOWS
      1002 = 766.4         $ H2 GAS CONSTANT
      1003 = 1             $ SWITCH TO EVALUATE V1 BLOCK
      1004 = 1             $ SWITCH TO EVALUATE ROECP AND HEVAL
      1005 = 5             $ NO OF LOOPS IN V1 BEFORE REEVALUATION
      1006 = 0             $ RESTART CASE IF = 1
      1007 = 0             $ CURRENT LOOP IN V1 SINCE LAST EVAL
      1008 = 0             $ CURRENT LOOP THRU V2
      1009 = 0             $ SWITCH USED IN SUBROUTIN YEILD
      1010 = 0             $ SWITCH = 1 FOR FINAL PARAMETER RUN
C     CONSTANTS USED IN NETWORK CGS CONDUCTORS
      1011 = 1.0           $ HIGH PRESS. MDOT*CP FACTOR
      1012 = 1.0           $ HIGH PRESS. MDOT*CP FACTOR
      1013 = 1.0           $ HIGH PRESS. MDOT*CP FACTOR
      1014 = 1.0           $ HIGH PRESS. MDOT*CP FACTOR
      1015 = 1.0           $ HIGH PRESS. MDOT*CP FACTOR
      1020 = 1.0           $ LOW PRESS. MDOT*CP FACTOR
      1031 = 1.0           $ H*A L.P. TO H.P. GAS FACTOR
      1032 = 1.0           $ H*A L.P. TO H.P. GAS FACTOR
      1033 = 1.0           $ H*A L.P. TO H.P. GAS FACTOR
      1034 = 1.0           $ H*A L.P. TO H.P. GAS FACTOR
      1035 = 1.0           $ H*A L.P. TO H.P. GAS FACTOR
      1040 = 1.0           $ H*A L.P. TO INNER CYL. WALL FAC.
      1050 = 1.0           $ H*A L.P. TO OUTER CYL. WALL FAC.
C     CONSTANTS USED FOR INPUT AND OUTPUT IN COMPRESSOR SUBROUTINE
      1100 = 1.       $ COMP. MDOT1 SET BY R100, T405, P1405 (LBM/HR)
      1101 = 379.0    $ MAX COMP. CYLINDER TEMP,300-3ST,379-4 (DEG F)
      1102 = 80.0     $ COOLING WATER INLET TEMP. (DEG F)
      1103 = 10.0     $ DT BETWEEN COOLING H2O INLET AND H2 OUTLET
      1104 = 80.0     $ GH2 OUTLET TEMP FROM COMP. (DEG F)
      1105 = 0.95     $ COMPRESSOR MECHANICAL EFFICIENCY
      1106 = 1.       $ GH2 DENSITY AT INLET CONDITIONS
      1107 = 1.       $ COMPRESSOR POWER CONSUMPTION KWS
      1108 = 6.988    $ FACTOR, =6.988 3STAGE, =10.48 4STAGE
      1109 = .9409    $ FACTOR, =.9409 3STAGE, =.8855 4STAGE
      1110 = 0.       $ VENT FRACTION = MDOT VENT/MDOT COMPRESSOR
      1111 = 1.       $ MDOT THRU H.P. HX2 LBM/HR (CAL. V1)
      1112 = 1.       $ MDOT THRU H.P. HX3 LBM/HR (CAL. V1)
      1113 = 1.       $ GN2 BOILOFF LBM/HR         (CAL. V1)
      1114 = 0.95     $ FRACTION OF MDOT THRU HX2 SIDE
      1115 = 50.0     $ GN2 FLOW RATE THRU HX3 LBM/HR
      1116 = 0.50     $ DAMPING FACTOR FOR GN2 BOILOFF MDOT ITERATION
C
C      CONSTANTS USED FOR HIGH TEMP HEAT EXCHANGERS (HX2/HX3)
C
      1131 = .98      $ HX2 EFFECTIVENESS
      1132 = .98      $ HX3 EFFECTIVENESS
      1133 = 1.0      $ CALCULATED HX2 UA BASED ON E AND FLOWS
      1134 = 1.0      $ CALCULATED HX3 UA BASED ON E AND FLOWS
      1135 = 1.       $ AVG HX2 COIL DIA.,FT        (CAL. EXEC)
      1136 = 1.       $ L.P. HX2 COLBURN J FACTOR (CAL. V1)
      1137 = 1.       $ CMINHX2                     (CAL. V1)
      1138 = 1.       $ CMINHX3                     (CAL. V1)
      1139 = 1.       $ PR NO. L.P. HX2             (CAL. V1)
```

```
      1140 = 1.      $ HC H.P. HX2               (CAL. V1)
      1141 = 1.      $ HC L.P. HX2               (CAL. V1)
      1142 = 1.      $ HC L.P. HX3               (CAL. V1)
      1143 = 1.      $ HC H.P. HX3               (CAL. V1)
      1145 = 0.248   $ CP OF GN2                 (CONST.)
      1146 = 1.      $ NTU,S HX2                 (CAL. V1)
      1147 = 1.      $ NTU,S HX3                 (CAL. V1)
      1150 = 1.      $ QDOT TO LN2 HX4,BTU/HR    (CAL. V1)
      1151 = 1.      $ HEAT OF EVAP.HX4,BTU/LBM  (CAL. V1)
      1152 = 1.      $ MAX POSSIBLE H AT HX1 OUT (CAL. YEILD)
      1153 = 1.      $ AVG ACT. Q TRANS IN HX1   (CAL. YEILD)
      1154 = 1.      $ MAX POSSIBLE Q TRANS HX1  (CAL. YEILD)
      1155 = 1.      $ EFFICIENCY OF HX1         (CAL. YEILD)
      1160 = 1.      $ PR NO. H.P. GH2 HX4       (CAL. V1)
      1161 = 1.      $ HC LN2 HX4                (CAL. V1)
      1162 = 1.      $ HA LN2 HX4                (CAL. V1)
      1163 = 1.      $ NTU,S LN2 HX4             (CAL. V1)
      1164 = 1.      $ EFFECTIVNESS OF LN2 HX4   (CAL. V1)
      1171 = 1.      $ ENTHLPY SAT. H2 VAP       (CAL. YEILD)
      1172 = 1.      $ ENTHLPY SAT. H2 LIQ.      (CAL. YEILD)
      1173 = 1.      $ ENTHLPY H.P. H2 GAS JT IN.(CAL. YEILD)
      1174 = 1.      $ QUALITY = VAPOR FRACTION  (CAL. YEILD)
      1175 = 1.      $ LIQ H2 YIELD, LBM/HR      (CAL. YEILD)
      1176 = 1.      $ CP OF SAT. H2 VAP         (CAL. V1)
      1177 = 1.      $ COMPRESSOR WATER (LBM/HR) (CAL. YEILD)
      1178 = 1.      $ CP OF SAT VAPOR IN THE DEWAR (CAL V1)
      1179 = 0.      $ = 0.NORMAL BOILOFF =1. LAUNCH OR LOADING
C   HEAT LEAK VARIABLES
      1200 = 1.713E-09    $ SIGMA
      1201 = 0.10         $ EMISSIVITY OF COLD BOX COMP.S.
      1202 = 0.10         $ EMISSIVITY OF INSIDE SURFACE OF MLI
      1203 = 0.0001       $ EFFECTIVE E THRU 20 LAYERS OF MLI
      1204 = 1.0          $ SURFACE AREA OF HX2 + HX3
      1205 = 1.0          $ SURFACE AREA OF LN2 BATH
      1206 = 28.27        $ SURFACE AREA OF 3 X 1.5 CONDENSOR
      1207 = 138.23       $ SURFACE AREA OF 4 X 10. COLD BOX
      1208 = 1.2          $ CONV. FILM COEFF. TO AMBIENT
      1209 = 1.0          $ HEAT LEAK INTO COLD BOX (CAL. V2)
      3000 = .0001   $ L.P. CONVERGENCE CRITERIA (ATM,S)
      3001 = 1.0     $ DP ON PRESSURE CONVERGENCE (CAL. V2)
      3002 = 0.0     $ H.P. H AT INLET TO HX1(T500)  ( CAL IN YEILD)
      3003 = 0.0     $ L.P. H AT CUTLET TO HX1(TS99) ( CAL IN YEILD)
      3004 = 0.0     $ % DQ HIGH TO LOW TEMP HX1     ( CAL IN YEILD)
      3005 = 0.0     $ YEILD CAL FROM HX1 INLET      ( CAL IN YEILD)
C****** PIPING SIZES
C  HIGH PRESSURE-COMPRESSOR TO HIGH TEMP EXCHANGER
     2000= 100.     $LENGTH,FT
     2001= .0833    $INSIDE DIA,FT
     2002= 10.      $NUMBER OF ELBOWS
     2003= 1.       $NUMBER OF VALVES
     2004= 1.       $NUMBER OF TEES
     2005= 1.       $NUMBER OF CHECK VALVES
C  HIGH PRESSURE-LN2 EXCHANGER
     2015= 2.       $DIA OF TOTAL LN2 BATH
     2016= 3.       $LENGTH,FT
     2017= 0.5/12.  $INSIDE DIA,FT
     2018= 1.       $FACTOR ON PIPING DELTA P TO ACCOUNT FOR PURIFIER
     2051= 2.       $ NO OF HELICAL LOOPS IN LINE
     2052= 1.       $ DIA. OF LOOP,FT.
     2053= 1.       $ PITCH, FT. (CAL. EXEC)
     2054= 1.       $ EFFECTIVE LENGTH PER LOOP, FT.(CAL. EXEC)
     2055= 1.       $ TEMPERATURE DIFF. BETWEEN BATH AND H2 LINE
C  HIGH PRESSURE-LOW TEMP EXCHANGER
     2019= 5.       $LENGTH PER PARALLEL PATH,FT
     2020= .02083   $INSIDE DIA,FT
     2021= 10.      $NUMBER OF TEES-TOTAL
     2022= 2.       $NUMBER OF ELBOWS-TOTAL
     2023= 5.       $NUMBER OF PARALLEL PATHS
C  LOW PRESSURE-H2 LIQ/VAPOR SEPARATOR TO LOW TEMP EXCHANGER
     2024= 1.       $LENGTH,FT
     2025= .0833    $INSIDE DIA,FT
     2026= 0.       $NUMBER OF ELBOWS
     2027= 0.       $NUMBER OF VALVES
     2028= 0.       $NUMBER OF TEES
     2029= 0.       $NUMBER OF CHECK VALVES
C  LOW PRESSURE-LOW TEMP EXCHANGER
C  OUTSIDE ANNULUS DIA(FT) DEFINED IN A10+1
C  INSIDE ANNULUS DIA(FT) DEFINED IN A10+2
C  TUBE DIA(FT) DEFINED IN A10+4
C  ANNULUS LENGTH(FT) DEFINED IN A10+5
C
C  LOW PRESSURE-LOW TEMP EXCHANGER TO HIGH TEMP H2 EXCHANGER
     2030= 1.       $LENGTH,FT
     2031= .0833    $INSIDE DIA,FT
     2032= 0.       $NUMBER OF ELBOWS
     2033= 0.       $NUMBER OF VALVES
     2034= 0.       $NUMBER OF TEES
     2035= 0.       $NUMBER OF CHECK VALVES
C  LOW PRESSURE-HIGH TEMP H2 EXCHANGER
     2036= 2.       $OUTSIDE DIA OF ANNULUS,FT
     2037= 1.5      $INSIDE DIA OF ANNULUS,FT
     2038= 3./16./12. $TUBE DIA,FT
     2039= 2.25     $ANNULUS LENGTH,FT
     2040= 10.      $NUMBER OF TEES
     2041= 2.       $NUMBER OF ELBOWS
     2042= 10.      $NUMBER OF PARALLEL PATHS
C  LOW PRESSURE-HIGH TEMP EXCHANGER TO COMPRESSOR
     2043= 100.     $LENGTH,FT
     2044= .1666    $INSIDE DIA,FT
     2045= 10.      $NUMBER OF ELBOWS
     2046= 1.       $NUMBER OF VALVES
     2047= 3.       $NUMBER OF TEES
     2048= 1.       $NUMBER OF CHECK VALVES
C****** PRESSURE CALCULATIONS -COMPRESSOR TO HIGH TEMP EXCHANGERS
     2100=1.        $VISCOSITY,LB/FT-HR
     2101=1.        $DENSITY,LB/CUFT
     2102=1.        $VELOCITY,FT/SEC
     2103=1.        $RE NO.
     2104=1.        $EFFECTIVE LENGTH,FT
     2105=1.        $DELTA P,ATM
     2106=1.        $AVG. TEMP. DEG K  (USED FOR PROPERTY LOOK-UP)
     2107=1.        $AVG. PRESSURE, ATM(USED FOR PROPERTY LOOK-UP)
     2108= 1.       $FRICTION FACTOR
C****** PRESSURE CALCULATIONS-HIGH TEMP H2 EXCH.   -HIGH PRESSURE SIDE
     2110=1.        $VISCOSITY,LB/FT-HR
     2111=1.        $DENSITY,LB/CUFT
     2112=1.        $VELOCITY,FT/SEC
     2113=1.        $RE NO.
     2114=1.        $EFFECTIVE LENGTH,FT(PER PARALLEL PATH)
     2115=1.        $DELTA P,ATM
     2116=1.        $AVG. TEMP,DEG.K
     2117=1.        $AVG. PRESSURE
     2118= 1.       $FRICTION FACTOR
     2119= 1.       $ HT SURFACE AREA OF TUBES HX2/HX3 (CAL. EXEC)
C****** PRESSURE CALCULATIONS -HIGH TEMP N2 EXCH.-HIGH PRESSURE SIDE
     2120=1.        $VISCOSITY,LB/FT-HR
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      2121=1.        $DENSITY,LB/CUFT
      2122=1.        $VELOCITY,FT/SEC
      2123=1.        $RE NO.
      2124=1.        $EFFECTIVE LENGTH,FT
      2125=1.        $DELTA P,ATM
      2126=1.        $AVG TEMP. K
      2128= 1.       $FRICTION FACTOR
C******PRESSURE CALCULATIONS-LN2 EXCH -HIGH PRESSURE SIDE
      2130=1.        $VISCOSITY,LB/FT-HR
      2131=1.        $DENSITY,LB/CUFT
      2132=1.        $VELOCITY,FT/SEC
      2133=1.        $RE NO.
      2134=1.        $EFFECTIVE LENGTH,FT
      2135=1.        $DELTA P,ATM
      2136=1.        $AVG TEMP
      2137=1.        $AVG PRESSURE
      2138= 1.       $FRICTION FACTOR
      2139= 1.       $ HT SURFACE AREA OF COIL LN2 HX4  (CAL. EXEC)
C******PRESSURE CALCULATIONS-LOW TEMP EXCH-HIGH PRESSURE SIDE
      2140=1.        $VISCOSITY,LB/FT-HR
      2141=1.        $DENSITY,LB/CUFT
      2142=1.        $VELOCITY,FT/SEC
      2143=1.        $RE NO.
      2144=1.        $EFFECTIVE LENGTH,FT
      2145=1.        $DELTA P, ATM
      2146=1.        $AVG TEMP
      2147=1.        $AVG PRESSURE
      2148= 1.       $FRICTION FACTOR
C******PRESSURE CALCULATIONS-H2 VAP/LIQ SEP TO LOW TEMP EXCH.-LOW P SIDE
      2150=1.        $VISCOSITY,LB/FT-HR
      2151=1.        $DENSITY,LB/CUFT
      2152=1.        $VELOCITY,FT/SEC
      2153=1.        $RE NO.
      2154=1.        $EFFECTIVE LENGTH,FT
      2155=1.        $DELTA P,ATM
      2156= 1.       $AVG TEMP
      2157= 1.       $AVG PRESSURE
      2158= 1.       $FRICTION FACTOR
C******PRESSURE CALCULATIONS-LOW TEMP EXCH-LOW PRESSURE SIDE
      2160=1.        $VISCOSITY,LB/FT-HR
      2161=1.        $DENSITY,LB/CUFT
      2162=1.        $GMAX, LB/HR-SQFT
      2163=1.        $A-MIN, SQFT
      2164=1.        $RE NO
      2165=1.        $XL = XT
      2166=1.        $FRICTION FACTOR
      2167=1.        $NUMBER OF INLINE TUBES
      2168=1.        $DELTA P,ATM
      2169=1.        $PITCH(FT)CENTER LINE TO CENTER LINE
      2266= 1.       $AVG TEMP -LOW TEMP EXCH-LOW PRESSURE SIDE
      2267= 1.       $AVG PRESSURE-LOW TEMP EXCH-LOW PRESSURE SIDE
      2268= 1.       $FRICTION FACTOR -LOW TEMP EXCH-LOW PRESSURE SIDE
C******PRESSURE CALCULATIONS-LOW TEMP TO HIGH TEMP EXCH-LOW P SIDE
      2170=1.        $VISCOSITY,LB/FT-HR
      2171=1.        $DENSITY,LB/CUFT
      2172=1.        $VELOCITY,FT/SEC
      2173=1.        $RE NO.
      2174=1.        $EFFECTIVE LENGTH
      2175=1.        $DELTA P, ATM
      2176=1.        $AVG TEMP
      2177=1.        $AVG PRESSURE
      2178=1.        $FRICTION FACTOR
C******PRESSURE CALCULATIONS-HIGH TEMP H2 EXCH-LOW PRESSURE SIDE
      2180=1.        $VISCOSITY,LB/FT-HR
      2181=1.        $DENSITY,LB/CUFT
      2182=1.        $GMAX,LB/HR-SQFT
      2183=1.        $A-MIN, SQFT
      2184=1.        $RE NO.
      2185=1.        $XL=XT
      2186=1.        $FRICTION FACTOR
      2187=1.        $NUMBER OF INLINE TUBES
      2188=1.        $DELTA P, ATM
      2189=1.        $PITCH(FT)-CENTER LINE TO CENTER LINE
      2286= 1.       $AVG TEMP-HIGH TEMP EXCH-LOW PRESSURE SIDE
      2287= 1.       $AVG PRESSURE-HIGH TEMP EXCH-LOW PRESSURE SIDE
      2288= 1.       $FRICTION FACTOR-HIGH TEMP EXCH-LOW PRESSURE SIDE
C******PRESSURE CALCULATIONS-HIGH TEMP EXCH TO COMPRESSOR-LOW P SIDE
      2190=1.        $VISCOSITY,LB/FT-HR
      2191=1.        $DENSITY,LB/CUFT
      2192=1.        $VELOCITY,FT/SEC
      2193=1.        $RE NO.
      2194=1.        $EFFECTIVE LENGTH,FT
      2195=1.        $DELTA P, ATM
      2196=1.        $AVG TEMP
      2197=1.        $AVG PRESSURE
      2198=1.        $FRICTION FACTOR
      END
      BCD 3ARRAY DATA
C*************************************************************************
C
    5 $ USER CONSTANT NUMBERS
        1, 1001, 1002, 1003, 1004, 1005, 1006, 1007, 1008
      1009, 1010, 1011, 1012, 1013, 1014, 1015, 1020
      1031, 1032, 1033, 1034, 1035, 1040, 1050, 1100, 1101
      1102, 1103, 1104, 1105, 1106, 1107, 1108, 1109, 1110
      1111, 1112, 1113, 1114, 1115, 1116
      1131, 1132, 1133, 1134, 1135, 1136, 1137, 1138
      1139, 1140, 1141, 1142, 1143, 1145, 1146, 1147, 1150
      1151, 1152, 1153, 1154, 1155
      1160, 1161, 1162, 1163, 1164, 1171, 1172, 1173, 1174
      1175, 1176, 1177, 1178, 1179, 1200, 1201, 1202, 1203, 1204
      1205, 1206, 1207, 1208, 1209, 3000, 3001, 3002, 3003, 3004
      3005, 2000, 2001, 2002
      2003, 2004, 2005, 2015, 2016, 2017, 2018, 2051, 2052
      2053, 2054, 2055, 2019, 2020, 2021, 2022, 2023, 2024
      2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032
      2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041
      2042, 2043, 2044, 2045, 2046, 2047, 2048, 2100
      2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2110
      2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119
      2120, 2121, 2122, 2123, 2124, 2124, 2126, 2128, 2130
      2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139
      2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148
      2150, 2151, 2152, 2153, 2154, 2155, 2153, 2157, 2158
      2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168
      2169, 2266, 2267, 2268, 2170, 2171, 2172, 2173, 2174
      2175, 2176, 2177, 2178, 2180, 2181, 2182, 2183, 2184
      2185, 2186, 2187, 2188, 2189, 2286, 2287, 2288, 2190
      2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, END
   10 $ CALCULATION ARRAY USED IN HXFLOW
        15.0/12., 7.5/12., 15., .25/12., 3.0, SPACE, 45, END
   11 $ TEMPORARY STORAGE ARRAY FOR L.P. HX1 HC
        SPACE, 30, END
   21 $ MDOT*CP AS F(T) FOR HIGH PRESS. HX GAS
        SPACE, 54, END
   22 $ MDOT*CP AS F(T) FOR LOW PRESS. HX GAS
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   SPACE, 54, END
 23 $ CONV. COEFF. AS F(T) FOR L.P. TO H.P. GAS
   SPACE, 54, END
 31 $ TEMPERATURE DEG K FOR GH2 PROPERITY EVALUATION (NORMAL GH2)
      20.4, 22.0, 24.7, 26.0, 28.2, 31.4, 33.0, 34.0, 36.0
      38.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 55.0, 60.0
      65.0, 70.0, 80.0, 90.0,100.0,150.0,250.0,300.0,350.0,END
 32 $ GH2 THERMAL CONDUCTIVITY AS F(T(A31)) (BTU/HR-FT-DEG F)
     4.287E-03, 5.761E-03, 8.282E-03, 9.495E-03, 11.55E-03
     13.79E-03, 14.433E-03, 14.83E-03, 15.62E-03, 16.42E-03
     17.22E-03, 17.962E-03, 18.70E-03, 19.44E-03, 20.18E-03
     20.92E-03, 22.65E-03, 24.39E-03, 26.10E-03, 27.80E-03
     31.32E-03, 34.79E-03, 38.37E-03, 56.69E-03, 90.21E-03
     104.9E-03, 118.4E-03, END
 33 $ GH2 VISCOSITY AS F(T(A31)) (LBM/HR-FT)
     1.234E-03, 1.469E-03, 1.865E-03, 2.055E-03, 2.378E-03
     4.041E-03, 4.222E-03, 4.331E-03, 4.554E-03, 4.777E-03
     5.000E-03, 5.204E-03, 5.406E-03, 5.613E-03, 5.817E-03
     6.021E-03, 6.489E-03, 6.957E-03, 7.394E-03, 7.831E-03
     8.658E-03, 9.442E-03, 10.18E-03, 13.54E-03, 19.19E-03
     21.67E-03, 24.12E-03, END
 35 $ GH2 H.P. ROE (LBM/CU FT) AS F(T(A31)) CAL FROM EQ
     SPACE,27,END
 37 $ GH2 L.P. ROE (LBM/CU FT) AS F(T(A31)) CAL FROM EQ
     SPACE,27,END
 33   $ TEMPORARY ARRAY USED TO CAL H.P. CP   STORED IN R3002
     SPACE, 27, END
 40   $ TEMPORARY ARRAY USED TO CAL L.P. CP   STORED IN R3003
     SPACE, 27, END
-100 $ H2 ENTHALPY VS TEMP AND PRESS (CAL/GM VS DEG K & ATMOS)
364,27,20.4, 22.0, 24.7, 26.0, 28.2, 31.4, 33.0, 34.0, 36.0
      38.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 55.0, 60.0
      65.0, 70.0, 80.0, 90.0,100.0,150.0,250.0,300.0,350.0
 1.0, 171.0,176.5,184.0,187.3,193.0,201.0,206.0,208.0,213.0
      218.0,223.0,228.0,233.2,238.3,243.0,248.0,260.6,273.0
      285.5,298.5,324.0,350.0,377.0,519.0,841.0,1010.0,1181.0
 1.5, 172.4,172.5,181.5,185.0,191.5,199.5,204.0,206.5,211.5
      216.5,222.0,227.0,232.0,237.0,242.0,247.5,260.0,272.5
      285.0,298.0,324.0,350.0,377.0,519.0,841.0,1010.0,1181.0
 3.0, 173.8,173.9,174.0,179.5,186.5,195.5,200.0,203.0,203.3
      213.5,219.5,224.5,230.0,235.0,240.2,245.5,258.5,271.5
      284.0,297.0,323.0,348.5,376.0,519.0,841.0,1010.0,1161.0
 6.0, 172.8,172.9,173.0,173.1,173.2,186.0,192.0,195.5,202.0
      206.0,214.0,220.0,225.0,230.3,236.0,242.0,255.0,263.5
      282.0,295.0,321.0,347.5,375.0,518.0,841.0,1010.5,1182.0
10.0, 164.8,164.9,165.0,165.1,165.2,165.3,177.0,182.0,191.0
      193.5,205.5,212.0,218.5,224.5,230.5,236.4,251.0,264.5
      278.5,292.0,319.0,346.0,373.0,516.0,841.5,1011.0,1183.5
13.0, 137.9,138.0,138.1,138.2,138.3,138.4,138.5,168.0,181.0
      191.0,199.0,206.5,214.0,221.0,227.5,234.0,248.0,262.5
      277.0,290.0,317.5,345.0,372.0,517.5,814.6,1011.0,1164.0
13.1,  69.0, 72.0, 78.0, 81.5, 90.0,105.0,136.4,158.0,181.9
      190.9,198.9,206.4,213.9,220.9,227.4,233.9,247.9,262.4
      276.9,289.9,317.4,344.9,371.9,517.5,841.6,1011.0,1184.0
20.0,  71.0, 73.0, 79.0, 81.0, 90.8,102.0,111.5,118.0,137.0
      151.5,178.5,190.5,199.5,206.0,216.0,223.3,240.0,255.5
      270.5,285.0,313.5,341.5,370.0,517.0,842.5,1012.0,1186.0
40.0,  75.0, 78.0, 85.0, 87.0, 93.6,102.5,108.5,113.0,126.0
      130.0,140.5,152.3,163.4,174.5,185.5,196.5,213.0,237.5
      255.5,272.5,304.0,334.0,363.0,515.0,843.5,1015.0,1189.0
60.0,  79.0, 81.0, 88.0, 91.0, 96.0,105.0,110.0,113.5,120.0
      127.5,135.5,144.3,153.3,162.0,171.0,180.0,202.5,223.3
      243.0,262.0,295.5,327.0,359.0,514.0,846.0,1017.5,1190.0
80.0,  81.0, 89.0, 93.0, 95.5,100.0,107.5,113.0,115.0,121.0
      127.3,134.0,142.3,150.5,158.0,166.3,174.5,195.0,215.2
      235.0,254.0,289.0,322.5,355.0,513.0,847.5,1020.0,1194.0
100.0, 85.0, 91.0, 96.0, 98.0,105.3,110.0,116.0,117.3,123.0
      129.0,135.5,142.0,149.3,156.2,164.5,172.0,192.0,210.7
      230.0,248.5,285.0,318.0,351.0,512.5,350.0,1023.0,1197.0
      END
   -101 $ CP(BTU/LBM-DEG R) VERSUS T (DEG K) AND P (ATM,S)
185,36
20.400, 20.750, 21.110, 22.780, 28.330, 33.890, 39.440, 45.000, 50.560
56.110, 61.670, 67.220, 72.780, 78.330, 83.890, 89.440, 95.000, 100.56
111.67, 122.78, 133.89, 145.00, 156.11, 167.22, 178.33, 189.44, 200.55
211.66, 222.77, 233.68, 245.00, 256.11, 267.22, 278.33, 299.44, 350.00
1.000,2.901, 2.869, 2.836, 2.710, 2.610, 2.560, 2.520, 2.520, 2.500
      2.500, 2.510, 2.520, 2.535, 2.555, 2.585, 2.615, 2.650, 2.658
      2.760, 2.835, 2.910, 2.980, 3.045, 3.100, 3.150, 3.200, 3.235
      3.270, 3.300, 3.330, 3.350, 3.365, 3.375, 3.395, 3.430, 3.430
1.361,2.980, 2.963, 2.964, 2.665, 2.650, 2.600, 2.545, 2.535, 2.515
      2.510, 2.515, 2.525, 2.540, 2.580, 2.585, 2.620, 2.650, 2.685
      2.765, 2.840, 2.915, 2.985, 3.050, 3.100, 3.150, 3.195, 3.235
      3.270, 3.300, 3.330, 3.345, 3.360, 3.380, 3.395, 3.430, 3.430
85.03,1.537, 1.569, 1.600, 1.753, 2.260, 2.825, 3.445, 3.645, 4.070
      4.120, 3.960, 3.750, 3.635, 3.510, 3.365, 3.260, 3.225, 3.195
      3.165, 3.150, 3.170, 3.200, 3.240, 3.275, 3.300, 3.320, 3.350
      3.375, 3.395, 3.415, 3.430, 3.435, 3.445, 3.450, 3.470, 3.470
102.0,1.388, 1.416, 1.445, 1.583, 2.041, 2.575, 3.310, 3.675, 3.790
      3.850, 3.835, 3.770, 3.680, 3.560, 3.425, 3.320, 3.275, 3.245
      3.210, 3.220, 3.210, 3.230, 3.270, 3.305, 3.325, 3.340, 3.365
      3.390, 3.410, 3.430, 3.440, 3.450, 3.455, 3.465, 3.475, 3.475
END
     200,SPACE,72,END     $ CP=F(T) FOR HIGH PRESS SELECTED
     201,SPACE,54,END     $ H=F(T) AT JT VALVE INLET
     202,SPACE,72,END     $ CP=F(T) FOR CL. LP. LOW PRESS SELECTED
    500 $ H2 SATURATED LIQUID  (H99=F(T99))
        20.4,54.0, 22.0,69.0, 24.7,77.0, 26.0,81.0
        28.2,89.0, 31.4,107., 33.0,138.4, END
    501,  SPACE,25, END $  (T99=F(H99))
    503 $ CP SAT. H2 VAPOR AS FUNCTION OF PRESS(ATM,S) (BTU/LBM-F)
        1.0, 2.92, 1.5, 3.00, 3.0, 3.30, END
    505 $ TANK SATURATED GAS PRESS. VS TEMP.
        19.03, .6830, 20.34, 1.02, 21.35, 1.36, 22.94, 2.04
        24.18,  2.72, 25.22, 3.40, 26.12, 4.08, 26.92, 4.76
        27.65,  5.44, 28.31, 6.12, 28.93, 6.80, END
    550 $ H2 SATURATED LIQUID  (H99=F(P))
         1.0,64.0, 1.5,69.0, 3.0,77.0, 3.9,81.0, 6.0,89.0
         10.,107., 13.,138.4,END
    560 $ H2 SATURATED VAPOR   (H10=F(P))
         1.0,171.0, 1.5,172.5, 3.0,174.0, 3.9,173.1
         6.0,173.2, 10.,165.3, 13.,138.4, END
    600 $ N2 SATURATED LIQUID  (H20=F(T20))
        70.0,-10.0, 77.0,0.0, 80.0,40.0, 90.0,190.0
       100.0,340.0, END
    601 $ N2 SATURATED VAPOR   (H22=F(T22))
        61.0,1220.0, 70.0,1300.0, 77.0,1330.0, 80.0,1350.0
        90.0,1375.0, 100.0,1415.0, END
    602 $ N2 VAPOR             (H23=F(T23))
       200.0,2210.0, 350.0,3260.0, END
C
    END
C*****************************************************************
    BCD 3EXECUTION
C
C   FIND RELATIVE NODE NUMBER WHERE TEMPERATURE CONVERSION STOPS
```

```
C
      DO 100 I = 1, NNT                       $ DO ON ALL NODES
      IF(ND(I).NE.1305) GO TO 100             $ CK NODE NUMBERS
      NDUM = I                                $ RELATIVE NODE NUMBER
      GO TO 200
  100 CONTINUE
  200 CONTINUE
C
C  IF THIS IS A FINAL PARAMETERS RUN CONVERT TEMPS TO DEGK
C
      IF(K1010.NE.1) GO TO 250
      DEGFTOK
  250 CONTINUE
C******PRESSURE DROP CALCULATIONS-EFFECTIVE LENGTHS
      R2104=R2000+(2.6*R2002+26.*R2003+5.56*R2004+6.2*R2005)*R2001
      R2154=R2024+(2.6*R2026+26.*R2027+5.56*R2028+6.2*R2029)*R2025
      R2174=R2030+(2.6*R2032+26.*R2033+5.56*R2034+6.2*R2035)*R2031
      R2194=R2043+(2.6*R2045+26.*R2046+5.56*R2047+6.2*R2048)*R2044
C******HEAT EXCHANGER GEOMETRY-HIGH TEMP H2
      R2189=((R2036-R2037)/2.+R2038)/(R2042+1.)  $PITCH
      R1135 = ((R1001*(R2036+R2037)/2.)**2+R2189**2)**0.5 $ DH
      R2187= (R2039/R2189)-1.    $ NO. OF INLINE COILS
      R2114 = R1135*R2187                    $ LENGTH PER PARALLEL PATH
      R2119 = R2042*R2114*R1001*R2038        $ TOT SURF. AREA OF TUBES
      R2114=R2114+(5.56*R2040/R2042+2.6*R2041/R2042)*R2038 $EFF LENGTH
      R2163= (3.14/2.)*(R2036+R2037)*(.5*(R2036-R2037)-R2038*R2042)
C            AREA MIN - SQFT
      R2165= R2189/R2038          $ XL =XT
C******HEAT EXCHANGER GEOMETRY- LOW TEMP
      COMPRES                     $ CAL. INITIAL FLOW RATE
      HXFLOWS                     $ CAL. LOW TEMP PARAMETERS
      R2169= A10+6                $ PITCH
      R2020= A10+4                $ TUBE DIAMETER
      R2023= A10+3                $ NO. OF PARALLEL TUBES = PATHS
      R2163= A10+33               $ TOTAL AMIN
      R2167= A10+8                $ NO. OF LENGTH WISE HELICAL LOOPS
      R2019= (((3.14*((A10+1)+(A10+2))/2.)**2+R2169**2)**.5)*(((A10+5)
     1       /R2169)-1.)   $ LENGTH PER PARALLEL PATH,FT
      R2144=R2019+(5.56*R2021/R2023+2.6*R2022/R2023)*R2020 $EFF LENGTH
      R2165 =R2169/(A10+4)                $ XL=XT
C
C  LN2 HX4 CALCULATIONS
C
C  PITCH = (L-DIA OF TUBE)/(NO. OF COILS + 1)
C
      R2053 = (R2016-R2017)/(R2051+1.)        $ PITCH
      R2054 = ((R1001*R2052)**2+R2053**2)**0.5 $ LENGTH PER COIL
      R2134 = R2054*R2051               $ TOTAL LENGTH
      R2139 = R1001*R2017*R2134         $ TOTAL SURF. AREA
C
C CALCULATE HEAT LEAK CONDUCTORS. THE RADK,S ARE BASED ON THE
C SURFACE EMISSIVITY TIMES THE AREA THIS GIVES A HIGH ESTIMATE
C FOR THE HEAT LEAK
C
C HX2 AND HX3 RADK,S
      R1204 = 2.*R1001*R2039*(R2036 + R2037) $ PIE*L*(DI+DO)
      G775 = R1200*R1204*R1201          $ SIGMA*A*E
C LN2 BATH
      R1205 = R1001*R2015*(R2016 + R2015/2.) $ PIE*D*(L + D/2)
      G780 = R1200*R1205*R1201          $ SIGMA*A*E
C HX1 INNER ANNULAS, AREA = R1040
      G771 = R1200*R1040*R1201          $ SIGMA*A*E
C HX1 OUTER ANNULAS, AREA = R1050
      G772 = R1200*R1050*R1201          $ SIGMA*A*E
C   CONDENSOR
      G785 = R1200*R1206*R1201          $ SIGMA*A*E
C   MLI TO TANK SKIN
      G790 = R1200*R1207*R1203          $ SIGMA*A*EFF. E
C   CONVECTION FROM COLD BOX OUTER SKIN TO AMBIENT
      G800 = R1208*R1207                $ H*A
C
C   HEAT OF EVAPORATION FOR LN2 (BTU/LBM)
C
      D1DEG1(T320,A600,HLIQ)            $ ENTHALPY SAT. N2 LIQUID
      D1DEG1(T320,A601,HVAP)            $ ENTHALPY SAT. N2 VAPOR
      R1151 = (HVAP-HLIQ)*1.8/28.016    $ HEAT OF EVAPORATION (BTU/LBM)
      BTEST = AMAX1(EBALNA,EBALSA)      $ MAX USED IN V1 AND V2 FOR EVAL
      DEGKTOF
      IF(K1006.EQ.1) GO TO 1000         $ RESTART RUN
      K1003 = K1004 = 1
 1000 CONTINUE
      STDSTL
      END
      BCD 3VARIABLES 1
C
C     LOGIC TO CONTROL V1 OPERATIONS
C
      ATEST = AMIN1(ABS(EBALNC),ABS(EBALSC))   $ MIN. POS. ENERGY BAL
      IF(K1003.EQ.1) GO TO 200
      IF(ATEST.LE.BTEST) GO TO 200             $ EVAL V1 IF TRUE
      K1007 = (K1007)+1
      IF(K1007.NE.K1005) GO TO 1000
  200 K1007 = K1003 = 0
C     IF(ITERCT.GT.5) EXTLIM = 1.0E-09
      IF(ITERCT.GT.6) GO TO 250
      K1004 = 1
      VARBL2
  250 CONTINUE
C
C   CONVERT TEMPS TO DEG K FOR PROPERTY EVALUATION
C
      DEGFTOK
C   REVALUATE NEW FLOW RATE
      COMPRES
C   REVALUATE FLOW THRU HX1 H.P. TUBE BUNDLES FOR CGS COND,S.
      DO 400 I = 1, 5
      J = I-1
      R1011+J = R1100/5.0                      $ MDOT EQUAL FLOW H.P.
  400 CONTINUE
C   REVALUATE FLOW THRU HX1 L.P. RINGS
      R1020 = R1100*(1.+R1110)/10.             $ COMP. + VENT FLOW L.P.
C
C   EVALUATE SYSTEM FLOW CONDUCTORS
C
      TAVG = (T305+T410)/2.
      D1D1DA(TAVG,A31,A38,CP)                       $ H.P. CP
      G30510 = CP*R1100                 $ MDOT*CP
C   CALCULATE SPLIT FLOW BETWEEN HX2 AND HX3 FROM R1114
      R1111 = R1114*R1100               $ MDOT THRU HX2 SIDE
      R1112 = R1100-R1111               $ MDOT THRU HX3 SIDE
      TAVG = (T410+T415)/2.             $ HX2 INLET H.P. SIDE
      D1D1DA(TAVG,A31,A38,CP)                 $ H.P. CP
      G41015 = R1111*CP                 $ SPLIT FLOW HX2
      TAVG = (T410+T425)/2.             $ HX3 INLET H.P. SIDE
      D1D1DA(TAVG,A31,A38,CP)                 $ H.P. CP
      G41025 = R1112*CP                 $ SPLIT FLOW HX3
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ORIGINAL PAGE IS
OF POOR QUALITY

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C
C     CALCULATE THE UA AND EFFECTIVNESS FOR THE HIGH TEMPERATURE HEAT
C     EXCHANGERS HX2/HX3. ALSO NEEDED FOR THIS IS THE LN2 BOILOFF.
C     THESE PARAMETERS ARE NECESSARY TO CAL. THE HX CROSS OVER CONDUCTORS
C
C     HIGH PRESSURE (H.P.) SIDE OF HX2
C
         R2116 = (T415+T420)/2.            $ AVG. TEMPERATURE
         D1D1DA(R2116,A31,A35,R2111)       $ H.P. DENSITY
         D1D1DA(R2116,A31,A38,CP)          $ H.P. SPECIFIC HEAT
         D1D1DA(R2116,A31,A33,R2110)       $ VISCOSITY
         D1D1DA(R2116,A31,A32,AK)          $ THERMAL CONDUCTIVITY
         R2112 = (0.0003537*R1111)/(R2111*(R2038**2)*R2042) $ VELOCITY
         R2113 = (3600.*R2111*R2112*R2038)/R2110 $ RE NO.
         R1136 = 0.23*R2113**(-0.2)*(1. + 3.5*(R2038/R1135))    $ J FACTOR
         R1139 = CP*R2110/AK               $ PR. NO.
         GMAX = R2110*R2113/R2038          $ VIS*RE/DIA
         R1140 = R1136*CP*GMAX*R1139**(-2./3.) $ HC H.P. HX2
         WHPHX2 = R1111*CP                 $ MDOT*CP FOR LATER USE
C
C     LOW PRESSURE (L.P.) SIDE OF HX2
C
         TAVG = (T450+T455)/2.             $ AVG. TEMPERATURE
         D1D1DA(TAVG,A31,A37,R2181)        $ L.P. DENSITY
         D1D1DA(TAVG,A31,A40,CP)                       $ L.P. SPECIFIC HEAT
         D1D1DA(TAVG,A31,A33,R2180)        $ VISCOSITY
         D1D1DA(TAVG,A31,A32,AK)           $ THERMAL CONDUCTIVITY
         R2182 = R1100*(1.+R1110)/R2183    $ GMAX =  MDOT/AMIN
         R2184 = R2039*R2182/R2180         $ RE NO. = D*GMAX/VIS
         R1136 = 0.26*R2184**(-0.4)        $ J FACTOR
         R1139 = CP*R2180/AK               $ PR NO.=CP*VIS/K
         R1141 = R1136*R2182*CP*R1139**(-2./3.) $ HC L.P. HX2=J*GMAX*CP*PR
         WLPHX2 = R1100*(1.+R1110)*CP      $ MDOT*CP FOR LATER USE
C
C     CALCULATE THE GN2 BOILOFF RATE FOR THE L.P. FLOW RATE OF HX3
C
         R2055 = T440-T320
         IF(R2055.GT.0.) GO TO 410
         T440 = T320 + 0.5
 410     R1150 = G1001*(T435-T320)*1.8     $ Q DOT TO LN2 BATH
         R1113 = R1150/R1151               $ GN2 FLOW RATE (LBM/HR)
C
C     ITERATE ON GN2 BOILOFF NEW CALCULATED VALUE AND OLD USED VALUE
C
         IF(ITERCT.LE.1) GO TO 420            $ FIRST PASS
         R1115 = R1115+R1116*(R1113-R1115)    $ NEW FLOW
 420     CONTINUE
         WLPHX3 = R1115*R1145              $ CONST MDOT*CP FOR LATER USE
         G32065 = WLPHX3                   $ MDOT*CP CONDUCTOR
C
C     CALCULATE HC FOR HX3 L.P. GN2 BY ADJUSTING FOR DIFFERENCES IN
C     BOTH FLOW RATE AND PROPERTIES BETWEEN L.P. SIDES OF HX2/HX3
C
C     HCN2/HCH2 = ((MDOTN2/MDOTH2)**.6)*.0936
C
         R1142 = R1141*0.0936*(R1115/(R1100*(1.+R1110)))**0.6 $HC L.P. HX3
C
C     EVALUATE HC ON THE H.P. SIDE OF HX3 BASED ON THE H.P. HX2 HC
C     AND THE FLOW RATE RATIO
C
         R1143 = R1140*(R1112/R1111)**0.8      $ HC H.P. HX3
         TAVG = (T425+T430)/2.             $ HX3 H.P. AVG. TEMP.
         D1D1DA(TAVG,A31,A38,CP)                       $ H.P. HX3 CP
         WHPHX3 = R1112*CP                 $ MDOT*CP FOR LATER USE
C
C     EVALUATE OVERALL UA FOR BOTH HX3/HX2
C
         R1133 = R2119*(1./(1./R1140 + 1./R1141)) $ HA HX2
         R1134 = R2119*(1./(1./R1142 + 1./R1143)) $ HA HX3
C
C     FIND MIN AND MAX FLOW RATES,EVALUATE NTU,S AND CALCULATE EFF
C
         CMINHX2 = R1137 = AMIN1(WHPHX2,WLPHX2)
         CMINHX3 = R1138 = AMIN1(WHPHX3,WLPHX3)
         CMAXHX2 = AMAX1(WHPHX2,WLPHX2)
         CMAXHX3 = AMAX1(WHPHX3,WLPHX3)
         CHX2 = CMINHX2/CMAXHX2            $ MIN/MAX RATIO HX2
         CHX3 = CMINHX3/CMAXHX3            $ MIN/MAX RATIO HX3
         R1146 = R1133/R1137               $ HX2 NTU,S = HA/CMIN
         R1147 = R1134/R1138               $ HX3 NTU,S = HA/CMIN
         XA1 = -R1146*(1.-CHX2)
         XA2 = EXP(XA1)
         R1131 = (1.-XA2)/(1.-CHX2*XA2)   $ EFF. HX2 COUNTERFLOW
         XA1 = -R1147*(1.-CHX3)
         XA2 = EXP(XA1)
         R1132 = (1.-XA2)/(1.-CHX3*XA2)   $ EFF. HX3 COUNTERFLOW
C
C     EVALUATE HX2 ONE WAY FLOW CONDUCTORS
C
         G45020 = G41555 = R1131*CMINHX2 $ EFF*MDOT*CP (MIN)
         G45055 = WLPHX2-R1131*CMINHX2   $ L.P. HX2 IN TO OUT
         G41520 = WHPHX2-R1131*CMINHX2   $ H.P. HX2 IN TO OUT
C
C     EVALUATE HX3 ONE WAY FLOW CONDUCTORS
C
         G42570 = G46530 = R1132*CMINHX3 $ EFF*MDOT*CP (MIN)
         G46570 = WLPHX3-R1132*CMINHX3   $ L.P. HX3 IN TO OUT
         G42530 = WHPHX3-R1132*CMINHX3   $ H.P. HX3 IN TO OUT
C
C     EVALUATE MDOT*CP CONDUCTORS FROM HX2/HX3 OUTLET TO MIXING VALVE
C
         TAVG = (T420 + T435)/2.          $ HC2
         D1D1DA(TAVG,A31,A38,CP)                      $ H.P. CP
         G42035 = R1111*CP                $ MDOT*CP
         TAVG = (T430 + T435)/2.          $ HC3
         D1D1DA(TAVG,A31,A38,CP)                      $ H.P. CP
         G43035 = R1112*CP                $ MDOT*CP
C
C     LN2 HEAT EXCHANGER EVALUATE HA. NTU,S AND EFFECTIVNESS
C     THIS IS FOR THE H.P. H2 TO TUBE ONLY THE BOILING LN2 HC IS HIGH
C
         TAVG = (T435+T440)/2.            $ H.P. GH2 AVG TEMP
         D1D1DA(TAVG,A31,A35,R2131)       $ H.P. H2 DENSITY
         D1D1DA(TAVG,A31,A38,CP)                      $ H.P. H2 CP
         D1D1DA(TAVG,A31,A33,R2130)       $ H2 VISCOSITY
         D1D1DA(TAVG,A31,A32,AK)          $ H2 THERMAL CONDUCTIVITY
         R2132 = (.0003537*R1100)/(R2131*R2017**2) $ VELOCITY
         R2133 = (3600.*R2131*R2132*R2017)/R2130 $ RE. NO.
         R1160 = CP*R2130/AK              $ H2 PR NO.
C    HC FOR LN2 HX4 BASED ON EQ.PG 136 JR. OF OIL AND GAS
         R1161 = (AK/R2017)*(0.039+0.138*R2017/R2052)
         R1161 = R1161*(R2133*R1160)**0.78        $ HC
         R1162 = R1161*R2139              $ HA
         R1163 = R1162/(R1100*CP)         $ NTU,S
         R1164 = 1.-EXP(-R1163)           $ EFFECTIVNESS
         G1001 = R1100*R1164*CP           $ EFF.*MDOT*CP
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      G43540 = (1.-R1164)*R1100*CP    $ (1.-EFF)*MDOT*CP
C
C    EVALUATE REMAINING NETWORK FLOW CONDUCTORS
C
      TAVG = (T440+T500)/2.           $ INLET TO HX1 AVG TEMP
      D1D1DA(TAVG,A31,A38,CP)                       $ H.P. CP
      G44050 = R1100*CP               $ MDOT*CP
      TAVG = (T539+T442)/2.           $ INLET TO JT VALVE AVG TEMP
      D1D1DA(TAVG,A31,A39,CP)                       $ H.P. CP
      G49942 = R1100*CP               $ MDOT*CP
      TAVG = (T455+T600)/2.           $ INLET TO L.P. HX1 AVG TEMP
      D1D1DA(TAVG,A31,A40,CP)                       $ L.P. CP
      G44560 = R1100*(1.+R1110)*CP    $ MDOT*CP
      TAVG = (T699+T450)/2.           $ INLET TO L.P. HX2 AVG TEMP
      D1D1DA(TAVG,A31,A40,CP)                       $ L.P. CP
      G49950 = R1100*(1.+R1110)*CP    $ MDOT*CP
      TAVG = (T455+T460)/2.           $ INLET TO L.P. VENT AVG TEMP
      D1D1DA(TAVG,A31,A40,CP)                       $ L.P. CP
      G45560 = R1100*(1.+R1110)*CP    $ MDOT*CP
      TAVG = (T460+T405)/2.           $ L.P. INLET TO COMPRESSOR
      D1D1DA(TAVG,A31,A40,CP)                       $ L.P. CP
      G46005 = R1100*CP               $ MDOT*CP
C
C    EVALUATE THE SEPERATOR AND VENT FLOW CONDUCTORS
C
      D1DEG1(T1310,A503,R1176)        $ CP FOR SAT. VAPOR F(P) IN COND
      G31045 = R1100*R1176            $ THRU SEPERATOR AND CONDENSOR
      IF(R1179.GT.1.0E-06) GO TO 450  $ BYPASS FOR LAUNCH/LOADING
      T309 = T310 + 1.0/1.8           $ T TANK = T COND + 1 DEG R
 450  D1DEG1(T309,A505,T1309)         $ TANK PRESS
      D1DEG1(T1309,A503,R1178)        $ TANK SAT CP =F(PRESS)
      G30945 = R1100*R1110*R1178      $ ULLAGE VENT TO MIXING VALVE
C
C    EVALUATE THE TEMPERATURE VARING CGS CONDUCTORS
C
      VARGS
C
C    MAKE THE HA CONDUCTORS SYMERTIC
C
     DO 500 I = 1, 69, 2
     J = I-1
      G701+I = G701+J
 500 CONTINUE
C
C    CONVERT TEMPS TO BACK TO DEG F FOR NETWORK SOLUTION
C
      DEGKTOF
1000  CONTINUE
      END
      BCD 3VARIABLES 2
C*******PRESSURE DROP CALCULATIONS*********
C  MASS RATE OF FLOW.LB-MASS/HR -DEFINED IN R1100 (COMPRESSOR FLOW)
C  RATIO OF VENT FLOW TO COMPRESSOR FLOW DEFINED IN R1110
C  AFTER COOLER OUTLET TEMP,DEG F,DEFINED IN R1104
C  COMPRESSOR INLET TEMP,DEG F,DEFINED IN T405
C  COMPRESSOR INLET PRESSURE,ATM,DEFINED IN T1405
C
C    CONSTANTS USED IN PRESSURE DROP EQUATION
C
      CON1 = 4./R1001/3600.           $ = .0003537
      CON2 = 1./144./14.7/2./32.2     $ = 7.336E-6
      CON3 = 1./144./14.7/2./32.2/(3600.)**2 $ = 5.66E-13
C
C*******HIGH PRESSURE SIDE******
C*******COMPRESSOR TO HIGH TEMP EXCH*******
        R2106 = ((R1104+T410)*.5 +460.)/1.8    $AVG.TEMP.,DEG.K
        R2107 =   (T1305 + T1410)*.5           $AVG. PRESSURE,ATM
        D1D1DA(R2106,A31,A23,R2100)            $AVG.VIS(LB/FT-HR)
        DENSITY(R2107,R2106,R2101)             $AVG.DEN(LB/CUFT)
        R2102 = (CON1*R1100)/(R2101*(R2001**2)) $VEL
        R2103 = (3600.*R2101*R2102*R2001)/R2100     $RE NO.
        IF(R2103 - 2300.)100,100,110
 100    R2108 = 64./R2103                           $FRICTION FACTOR
        GO TO 120
 110    R2108 = .0056 +.5/(R2103**.32)
 120    CONTINUE
        R2105 = ( CON2*R2108*R2104*R2101*(R2102**2)/R2001) $DEL-P
        T1410 = T1305 - R2105      $NEW PRESSURE
C*******HIGH TEMP H2 EXCH**********
        R2116 = ((T410 + T420)*.5 +460.)/1.8  $AVG.TEMP
        R2117 = (T1410 + T1435)*.5            $AVG.PRESSURE
        D1D1DA(R2116,A31,A33,R2110)  $VIS
        DENSITY(R2117,R2116,R2111)   $DEN
        R2112=(CON1*R1111)/(R2111*(R2038**2)*R2042) $VEL
        R2113= (3600.*R2111*R2112*R2038)/R2110    $RF NO.
        IF(R2113 -2300.)130,130,140
 130    R2118 = 64./R2113
        GO TO 150
 140   R2118 = .0056 + .5/(R2113**.32)
 150   CONTINUE
       R2115 = R2042*(CON2*R2118*R2114*R2111*(R2112**2)/R2038)
C
C   GN2 SIDE H.T. HX3 CAL DP FROM H2 SIDE OF HX2 AND RATIOS OF DENSITY
C   AND FLOW RATES DP3 = DP2*(ROE2/ROE3)*(MDOT3/MDOT2)**2
C
       R2126 = ((T410 + T430)*.5 + 460.)/1.8 $ AVG TEMP
       DENSITY(R2117,R2126,R2121)      $ DEN
       R2125 = R2115*(R2111/R2121)*((1.-R1114)/R1114)**2  $ DEL-P
       T1435 = T1410-(R2115+R2125)     $ NEW PRESSURE AT MIXING VALVE
C******* LN2 EXCHANGER *******
       R2136 = ((T435+ T440)*.5 + 460.)/1.8      $ TEMP
       R2137 = (T1435 + T1440)*.5                $ PRESSURE
       D1D1DA(R2136,A31,A33,R2130)               $ VIS
       DENSITY(R2137,R2136,R2131)                $ DEN
       R2132 = (CON1*R1100)/(R2131*(R2017**2)) $VEL
       R2133 =(3600.*R2131*R2132*R2017)/R2130     $RE NO.
       IF(R2133-2300.)160,160,170
 160   R2138 = 64./R2133
       GO TO 180
 170   R2138 = .0056 +.5/(R2133**.32)
 180   CONTINUE
       R2135 = (CON2*R2138*R2134*R2131*(R2132**2)/R2017)
       T1440 = T1435 - R2135
C******** LOW TEMP EXCHANGER ********
       R2146 = ((T440+T410)*.5 + 460.)/1.8          $TEMP
       R2147 = (T1440+T1440)*.5                     $PRESSURE
       D1D1DA(R2146,A31,A33,R2140)                  $VIS
       DENSITY(R2147,R2146,R2141)                   $DENSITY
       R2142 =(CON1*R1100)/(R2141*(R2020**2)*R2023)  $VEL
       R2143 = (3600.*R2141*R2142*R2020)/R2140            $RE NO.
       IF(R2143-2300.)190,190,200
 190   R2148 = 64./R2143
       GO TO 210
 200   R2148 = .0056 + .5/(R2143**.32)
 210   CONTINUE
       R2145 =R2023*(CON2*R2148*R2144*R2141*(R2142**2)/R2020)
```

```
      T1442 = T1440- R2145
C*******LOW PRESSURE SIDE *******
C*******HIGH TEMP EXCH TO COMPRESSOR *******
      R2196 = ((T405+T460)*.5 +460)/1.8         $TEMP
      R2197 =  (T1405+T1460)*.5               $PRESSURE
      D1D1DA(R2196,A31,A33,R2190)             $VIS
      DENSITY(R2197,R2196,R2191)              $DEN
      R2192 = (CON1*R1100)/(R2191*(R2044**2))  $VEL
      R2193 = (3600.* R2191*R2192*R2044)/R2190     $RE NO.
      IF(R2193-2300.)220,220,230
 220  R2198 = 64./R2193
      GO TO 240
 230  R2198 = .0056 + .5/(R2193**.32)
 240  CONTINUE
      R2195 =(CON2*R2198*R2194*R2191*(R2192**2)/R2044)
      T1460 = T1405 + R2195
C******* HIGH TEMP EXCHANGER -LOW PRESSURE SIDE*******
      R2286 =((T450+T430)*.5 +460.)/1.8      $TEMP
      R2287 =(T1450+T1460)*.5                $PRESSURE
      D1D1DA(R2286,A31,A33,R2180)            $VIS
      DENSITY(R2287,R2286,R2181)             $DEN
      R2182 = R1100*(1.+R1110)/R2183         $GMAX
      R2184=  R2038 * R2182/R2180                 $RE NO.
      R2186=  (.176+.32*R2185/((R2185-1)**(0.43+1.13/R2185)))
     1 /(R2184**.15)        $FRICTION FACTOR
      R2188 = CON3*R2186*R2187*(R2182**2)/R2181  $DELTA P
      T1450 = T1460 + R2188
C******* LOW TEMP TO HIGH TEMP EXCHANGER -LOW PRESSURE SIDE*******
      R2176 = ((T450+T699)*.5 +460.)/1.8        $TEMP
      R2177 = (T1450+T1699)*.5                  $PRESSURE
      D1D1DA(R2176,A31,A33,R2170)               $VIS
      DENSITY(R2177,R2176,R2171)                $DEN
      R2172 = (CON1*R1100*(1.+R1110))/(R2171*(R2031**2)) $ VEL
      R2173 = (3600.*R2171*R2172*R2031)/R2170                 $RE NO.
      IF(R2173-2300.)250,250,260
 250  R2178 = 64./R2173
      GO TO 270
 260  R2178 = .0056 + .5/(R2173**.32)
 270  CONTINUE
      R2175 = (CON2*R2178*R2174*R2171*(R2172**2)/R2031)  $DEL P
      T1699 = T1450+ R2175
C*******LOW TEMP EXCH- LOW PRESSURE SIDE*********
      R2266 = ((T699+T600)*.5 +460.)/1.8        $TEMP
      R2267 = (T1699+T1600)*.5                  $PRESSURE
      D1D1DA(R2266,A31,A33,R2160)               $VIS
      DENSITY(R2267,R2266,R2161)                $DEN
      R2162 =  R1100*(1.+R1110)/R2163           $G-MAX
      R2164 = (A10+4)*R2162/R2160     $ RE NO.
      R2166 =   (.176+.32*R2165/((R2165-1.)**(.43+1.13/R2165)))/
     1 (R2164**.15)                           $FRICTION FACTOR
      R2168 = (CON3*R2166*R2167*(R2162**2)/R2161)  $DELTA P
      T1600 = T1699 + R2168
C******* H2 LIQ/VAP SEPARATOR TO LOW TEMP EXCH.*******
      R2156 = ((T310+T600)*.5 +460)/1.8         $TEMP
      R2157 =  (T1310+T1600)*.5                 $PRESSURE
      D1D1DA(R2156,A31,A33,R2150)               $VIS
      DENSITY(R2157,R2156,R2151)                $DEN
      R2152 = (CON1*R1100)/(R2151*(R2025**2)) $VELOCITY
      R2153 = (3600.*R2151*R2152*R2025/R2150)     $RE NO.
      IF(R2153-2300.)280,280,290
 280  R2158 = 64./R2153
      GO TO 300
 290  R2158 = .0056 + .5/(R2153**.32)
 300  CONTINUE
      R2155 =  CON2*R2158*R2154*R2151*(R2152**2)/R2025 $DELTA P
C
C   LOGIC TO SET BACKUP SWITCH AND REITERATE IF DID NOT CONVERGE
C
      TIMEND = 0.                           $ ZERO OUT TIME
      POLD = T1310                          $ OUTLET P OF JT VALVE
      T1310 = PNEW = T1600 + R2155          $ NEW PRESSURE
      R3001 = ABS(PNEW-POLD)                $ DP IN ATM,S
      IF(R3001.GT.R3000) GO TO 325          $ DIDN,T CONVERGE
      WRITE(6,1003) K1008, R3001
F1003 FORMAT(//20X,* PRESSURE CONVERGED AFTER LOOP*,I3,
F    1 * THE FINAL PRESSURE DIF. WAS * G11.5,* ATM,S*)
      GO TO 375
C
C   PROCEDURE DID NOT CONVERG -- INCREMENT LOOPS, SET BACKUP
C   REEVALUATE PROPERTIES -- WRITE PRESSURES AND REITERATE
C
 325  K1008 = (K1008) + 1
      IF(K1008.LT.20) GO TO 350
C
C   TOO MANY LOOPS-- END PROBLEM
C
      WRITE(6,1001) K1008,POLD, PNEW
F1001 FORMAT(1H1,20X*PRESSURE CONVERGENCE FAILED AFTER*,I3,* LOOPS */
F    1,20X* POLD = *, G11.5, *PNEW = *, G11.5)
      GO TO 500
 350  CONTINUE
      WRITE(6,1002) K1008,POLD, PNEW
F1002 FORMAT(20X*PRESSURE ITERATIONS CONTINUING  *,I3,* LOOPS */
F    1,20X* POLD = *, G11.5, *PNEW = *, G11.5)
      TIMEND = 1.                            $ REITERATE
 375  IF(K1004.EQ.1) GO TO 400
      IF(ATEST.LE.BTEST) GO TO 400
      GO TO 500
C
C   EVALUATE THE H.P. AND L.P. DENSITY AND CP ARRAYS
C
 400  ROECP                                 $ DENSITY AND CP EVAL
C
C   EVALUATE A NEW ARRAY OF HX1 L.P. HC VS TEMP AT NEW PRESS,S.
C
      HEVAL
      K1004 = 0
 500  CONTINUE
C
C   CALCULATE THE YEILD AND THE JT VALVE OUTLET TEMPERATURE
C
      YEILD
C
C   CALCULATE THE HEAT LEAK THRU THE MLI INTO THE COLD BOX
C
      R1209 = C790*((T1500+460.)**4.-(T1000+460.)**4.)
      END
BCD 3OUTPUT CALLS
      VARBL2
      DEGFTOK
      TPRINT
      R1113 = R1113*3.55                    $ LN2 BOILOFF(GAL/DAY)
      PRINTRS
      R1113 = R1113/3.55                    $ LN2 BOILOFF(LBM/HR)
      PRINTA(4HA10+,A10+1,35,1)
      PRINTA(4HA31+,A31+1,M31,1)
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ORIGINAL PAGE IS
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        PRINTA(4HA23+,A23+1,M23,1)
        PRINTA(4HA35+,A35+1,M35,1)
        PRINTA(4HA37+,A37+1,M37,1)
        PRINTA(4HA38+,A39+1,M38,1)
        PRINTA(4HA40+,A40+1,M40,1)
        PRINTA(5HA200+,A200+1,M200,1)
        PRINTA(5HA202+,A202+1,M202,1)
        PRINTA(1HG,G(1),NGT,1)
        IF(ITERCT.GT.10) CALL STOREP           $ STORE FOR RESTART
        DEGKTOF
        END
        BCD 3SUBROUTINES
F       SUBROUTINE ROECP
FCALL COMMON
C
C     THIS SUBROUTINE CALCULATES THE HIGH AND LOW PRESSURE
C     DENSITY AND SPECIFIC HEAT ARRAYS AS FUNCTION OF TEMPERATURE
C     BASED ON THE AVERAGE HIGH AND LOW CYCLE PRESSURES
C
        PAVGH = (T1305+T1442)/2.
        PAVGL = (T1310+T1405)/2.
C
C     CALCULATE THE HIGH AND LOW PRESSURE DENSITY ARRAYS
C
        DENARY(PAVGH,A31,A35)             $ H.P. ROE = F(T(A31))
        DENARY(PAVGL,A31,A37)             $ L.P. ROE = F(T(A31))
C
C     EVALUATE THE HIGH AND LOW PRESSURE CP ARRAYS
C
        BVSPDA(PAVGH,A101,A200)           $ H.P. CP VS  T(A101)
        BVSPDA(PAVGL,A101,A202)           $ L.P. CP VS  T(A101)
        WRITE(6,1001) ITERCT, PAVGH, PAVGL
F1001   FORMAT(10X,*LOOP=*I3,*HIGH PRESSURE=*G11.3* ATMS LOW PRESSURE=*
F      1 G11.3* ATMS *)
C
C     INTERPOLATE THE CP IN A200/202 TO CP FOR TEMPS IN A31
C
        ITOT = M31                        $ INTERGER COUNT
        DO 100 I = 1, ITOT
        D1DEG1(A31+I,A200,A38+I)          $ H.P. CP,S
        D1DEG1(A31+I,A202,A40+I)          $ L.P. CP,S
100     CONTINUE
C
C     FORM A DOUBLET ARRAY TEMP AND CP,S FOR USE IN VARG,S
C
        JOIN(ITOT,A31+1,A38+1,A21+1)      $ H.P. CP VS T
        JOIN(ITOT,A31+1,A40+1,A22+1)      $ L.P. CP VS T
F      RETURN
F      END
F      SUBROUTINE PRINTRS
FCALL COMMON
       WRITE(6,1000)
       WRITE(6,1001) (M5+I,I,R(I),I=1,NCON)
F1000  FORMAT(1H1,20X,* USER CONSTANTS *)
F1001  FORMAT(1X,5(* R*,I4,* (*,I3,*) = *,G11.4))
F      RETURN
F      END
F      SUBROUTINE SWITCH(A,B)
C
C     ......THIS SUBROUTINE SWITCHES  T=F(H) ARRAYS TO H=F(T) ARRAYS
C
F      DIMENSION A(1),B(1)
F      NT  =A(1).OR.0
```

```
F       IF((NT.AND.1).EQ.1)   CALL ARYER1(6LSWITCH,A)
F       B(1)  =A(1)
F       DO 100 I=2,NT,2
F       IF(I.GT.NT)    GO TO 100
F       J  =I+1
F       B(I)  =A(J)
F       B(J)  =A(I)
F100    CONTINUE
F       RETURN
F       END
F        SUBROUTINE HXFLOWS
FCALL COMMON
C*************************************************************
C
C     THIS SUBROUTINE CALCULATES THE PARAMETERS NECESSARY TO
C     DEFINE THE GIAUQUE-HAMPSON HEAT EXCHANGER PACKAGE
C     INPUT ARRAY A10 IS USED WITH THE FOLLOWING VARIABLES
C
C     A10+1--OUTSIDE PACKAGE DIAMETER                            INPUT
C     A10+2--INSIDE PACKAGE DIAMETER                             INPUT
C     A10+3--NUMBER OF PARA. TUBES IN A CROSS SEC.               INPUT
C     A10+4--TUBE DIAMETER                                       INPUT
C     A10+5--PACKAGE LENGTH                                      INPUT
C     A10+6--LONG. AND TRAN. PITCH                               CALCULATED
C     A10+7--LONG. AND TRAN. TUBE SPACING (FRACTION OF DIA)      CALCULATED
C     A10+8--NUMBER OF PARA. HELICAL LOOPS                       CALCULATED
C     A10+9--TOTAL CROSS SECTIONAL AREA                          CALCULATED
C     A10+10-RING SEGMENT CROSS SECTIONAL AREA                   CALCULATED
C     A10+11-INSIDE PACKAGE DIAMETER                             CALCULATED
C     A10+12---A10+16-RING SEGMENT DIAMETERS                     CALCULATED
C     A10+17-FACTOR FOR TUBES VERSES LENGTH LINEAR EQ.           CALCULATED
C     A10+18-LOGITUDINAL TUBES PER NODE                          CALCULATED
C     A10+19---A10+20-NOT USED
C     A10+21---A10+25-TUBES IN EACH RING SEGMENT                 CALCULATED
C     A10+26---A10+30-TUBE SURFACE AREA PER NODE                 CALCULATED
C     A10+31-INSIDE SURFACE AREA OF INNER ANNULAS                CALCULATED
C     A10+32-INSIDE SURFACE AREA OF OUTTER ANNULAS               CALCULATED
C     A10+33-MINIMUM FLOW AREA BETWEEN TUBES                     CALCULATED
C     A10+34-FACTOR USED IN L.P. SIDE OF HX1 H EQUATION          CALCULATED
C     CHECK THAT TUBE SPACEING AND NO. ARE CONSISTENT AND THAT
C     A GAP OF AT LEAST Y*DIA EXIST BETWEEN THE TUBES
C
        Y = 0.1                               $ DIA FRACTION
        A10+20 = 0.5*(A10+1-A10+2) + A10+4
        A10+20 = A10+20/(A10+4*(Y*A10+4 + 1.))
        A10+20 = A10+20 - 1.
        IF((A10+3).LE.(A10+20)) GO TO 5
        A10+3 = AINT(A10+20)                  $ READJ. NO. OF TUBES
 5     A10+6 = ((A10+1-A10+2)/2.+A10+4)/(1.+A10+3) $ LONG./TRANV. P
       A10+7 = (A10+6/A10+4)-1.                 $ TUBE SPACE FRACTION OF DIA
       A10+8 = A10+5/A10+6                      $ NO. OF LONG. LOOPS
C
C     CALCULATE RADIAL SPACEING OF EACH NODAL VOLUME
C
       A10+9 = (R1001/4.)*(A10+1**2-A10+2**2) $ CROSS SEC. AREA
       A10+10 = A10+9/5.                        $ CROSS SEC. AREA PER NODE
       A10+11 = A10+2                           $ INNER DIAMETER
       A10+19 = 4.*A10+10/R1001                 $ CONST.
       DO 10 I = 1, 5                           $ CAL. RING DIA.S
       A10+11+I = SQRT(A10+19 + A10+10+I**2) $ RING DIA.
 10    CONTINUE
C
C     CALCULATE THE NUMBER OF TUBES PER RING SEGMENT BASED ON
```

```
C     A LINEAR RADIAL SPACEING OF THE TUBES AND THE NO. OF TUBES
C     BETWEEN EACH RING SEGMENT
C
        A10+17 = A10+3/(A10+16-A10+11)          $ TUBE LOC. EQ. FACTOR
        A10+18 = A10+8/5.                        $ LONG. TUBES PER NODE
        DO 20 I =1, 5                            $ TRANV. TUBES PER NODE
        A10+20+I = A10+17*(A10+11+I-A10+10+I)
C
C     LOAD INITIAL MDOT INTO H.P. FLOW COND. CONSTANTS (UPDATED IN V1)
C
        J = I-1                                  $ INDEX COUNTER
        R1011+J = (A10+20+I/A10+3)*R1100         $ FLOW THRU EACH TUBE BUNDEL
 20     CONTINUE
C
C     CALCULATE THE TUBE SURFACE AREA PER NODAL VOLUME =
C     NO OF RADIAL TUBES PER NODE*NO OF LONG. TUBES PER NODE
C     *AVG.COIL LENGTH*TUBE CIRCUMFERENCE
C
        DO 30 I = 1, 5                           $ DO ON DIAMETERS
        X1 = (A10+11+I + A10+10+I)/2.
        X2 = (R1001*X1**2 + A10+6**2)**0.5       SAVG COIL LENGTH
        A10+25+I = A10+18*A10+20+I*X2*R1001*A10+4 $ TUBE AREA PER NODE
C     LOAD SURF. AREAS INTO COND. CONSTANTS DIVIDE BY 2 NODES PER RING
        J = I -1
        R1031+J = A10+25+I/2.                    $ NODAL SURFACE AREA
 30     CONTINUE
C     CALCULATE INSIDE AND OUTSIDE CYLINDER AREAS
        A10+31 = R1001*A10+2*A10+5               $ INSIDE TUBE AREA
        R1040 = A10+31/10.                       $ COND. CONST.
        A10+32 = A10+1*R1001*A10+5               $ OUTSIDE TUBE AREA
        R1050 = A10+32/10.                       $ COND. CONST
C
C     CALCULATE THE MIN. FLOW AREA BASED ON AN AVERAGE DIAMETER FOR H EQ
C     MULTIPLY THIS NUMBER BY THE NUMBER OF TUBES IN RING NODE 1 AND
C     THE RESULT SHOULD BE THE SAME FOR EACH RING NODE
C
        DAVG = (A10+1+A10+2)/2.                  $ AVERAGE DIAMETER
        DAP = DAVG + A10+4*A10+7                 $ AVG DIA + TUBE SPACE
        A10+33 = R1001*(DAP**2-DAVG**2)/4.       $ MIN FLOW AREA
        A10+33 = A10+33*A10+3                    $ TOT MIN FLOW AREA FOR HX1
C
C     CALCULATE THE CONST. USED FOR THE L.P. SIDE OF HX1 H EQUATION
C
        A10+34 = 0.26*A10+4**-0.4                $ CONST. FOR L.P. HX1 H
F       RETURN
F       END
F        SUBROUTINE HEVAL
FCALL COMMON
C
C     THIS SUBROUTINE CALCULATES A DOUBLET ARRAY OF TEMP. VERSUS HEAT CONV
C     COEFFICIENT FOR THE L.P. SIDE OF HX1 BASED ON THE FOLLOWING EQUATION
C     FROM BARRON,S BOOK PG. 136:
C     **** JSUBH = (HC/CSUP*G)*PRNO.**2/3 = 0.26*RE**(-0.4) *****
C     THIS EXPANDS TO :
C     **** HC = 0.26*DE**-0.4*GMAX**.6*CSUBP**1/3*K**2/3*VIS**-4/15
C     0.26*DE**-0.4 IS CONST (A10+34) AND EVALUATED IN HXFLOWS
C
         NN = M31                       $ INTERGER COUNT FROM TEMP. ARRAY
         GMAX = (R1100*(1.+R1110)/A10+33)**0.6 $ MDOT/AMIN TO .6 POWER
         DO 10 I = 1,NN
         CP = A40+I                     $ L.P. CSUBP AT T(I)
         AK = A32+I                     $ THERMAL COND. AT T(I)
         VIS = A33+I                    $ VISCOSITY AT T(I)
         HC = A10+34*GMAX*CP**(1./3.)*AK**(2./3.)*VIS**(-4./15.) $ HC
         A11+I = HC                      $ LOAD INTO TEMPORARY ARRAY
 10      CONTINUE
C
C     FORM DOUBLET ARRAY OF TEMP VERSUS HC
C
         NNN = M31                       $ INTERGER COUNT OF ARRAY
         JOIN(NNN,A31+1,A11+1,A23+1) $ FORMS DOUBLET ARRAY
F        RETURN
F        END
F        SUBROUTINE DENARY(P,TX,ROE)
F        DIMENSION TX(1), ROE(1)
C
C     THIS SUBROUTINE COMPUTES AN ARRAY OF DENSITY FOR THE TEMPERATURES
C     GIVER IN ARRAY TX AND FOR ONE PRESSURE P
C     P----PRESSURE IN ATMOSPHERES
C     TX---TEMPERATURE ARRAY IN DEG K
C     ROE--CALCULATED DENSITY ARRAY IN LBM/CU FT
C
C     THE METHOD WAS DEVELOPED BY R.K. MCMORTIE 1/6/77
C     THE VAN DER WALL EQUATION IS USED FOR A FIRST ESTIMATE OF
C     DENSITY. NEWTON,S METHOD IS THEN USED TO SOLVE FOR THE DENSITY
C     AS A FUNCTION OF BOTH TEMP AND PRESSURE UNTIL A .OLERRANCE OF EPS
C     AN ERROR CORRECTION PARAMETER IS THEN APPLIED TO THE ITERATIVE ANS.
C
         NTX = TX(1).OR.0                $ INTERGER CNT. OF TEMP ARRAY
         NTY = NTX + 1                   $ LAST ARRAY VALUE
         EPS = .00001                    $ CONVERGENCE TOLERANCE
C
C     CONVERT TEMP,S. TO DEG R
C
         DO 10 I = 2, NTY
F        TX(I) = TX(I)*1.8
 10      CONTINUE
C
C     BASE A FIRST OF ROE ON VAN DER WALL,S EQUATION
C
         DO 20 I = 2,NTY
F        ROE(I) = 2.762*(P/TX(I))
 20      CONTINUE
C
C     EVALUATE THE ERROR CORRECTION PARAMETER (FUNCTION OF P ONLY)
C
         ER3 = 1.-EXP(-(P/20.)**4.) $ ERROR COR.
C
C     EVALUATE THE FUNCTION (F) AND THE PARTIAL OF F WITH RESPECT TO
C     ROE (PF) AS A FUNCTION OF TEMP. FOR USE IN NEWTON,S METHOD
C
         DO 40 I = 2,NTY                 $ DO FOR EACH TEMP
         LOOP = 1                        $ INITIALIZE ITERATION COUNTER
         XO = ROE(I)
         XA = 0.06472*P + 0.11049*TX(I)
         ER1 = 0.2*EXP(-(TX(I)/1.05)**5.96)
         ER2 = (0.00138*P-0.06944)*(2000./((TX(I)-126.)**2+2000.))
         ER = (ER1+ER2)*ER3
 25      XO2 = XO**2
         F = XO**3.-4.721*XO2+XO*XA-0.30555*P
         PF = 3.*XO2 - 9.442*XO + XA
         XN = XO - (F/PF)                $ NEWTONS METHOD
         TEST = XN-XO
         IF(ABS(TEST).LE.EPS) GO TO 35 $ METHOD CONVERGED
C
C     NO CONVERGENCE CHECK LOOPS AND REITERATE
```

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C
       IF(LOOP.GT.10) GO TO 30      $ NO SOLUTION
       LOOP = LOOP + 1
       XO = XN
       GO TO 25
 30    CONTINUE
       WRITE(6,1001) LOOP, I,P,TX(I), ROE(I), TEST, XN, XO, F, PF,ER
F1001  FORMAT(//20X,*DENSITY FAILED TO CONVERGE AFTER*,I5,*LOOPS* /
F     1,20X,* RELATIVE ARRAY LOCATION *,I3,* P =*G11.3 * TX(I) = * G11.3/
F     2,20X * ROE(I) = * G11.3,* TEST = * G11.3, * XN = * G11.3 ./
F     3,20X,* XO = * G11.3, * F = * G11.3, * PF = * G11.3* ER = *G11.3)
F35    XXX = XN/(1.-ER)
       IF(XXX.GE.0.) GO TO 37
       WRITE(6,1002) LOOP, I,P,TX(I),XXX, ROE(I), TEST, XN, XO, F, PF,ER
F1002  FORMAT(//20X,*DENSITY IS NEGATIVE               *,I5,*LOOPS* /
F     1,20X,* RELATIVE ARRAY LOCATION *,I3,* P =*G11.3 * TX(I) = *G11.3,/
F     2,XXX=*G11.3* ROE(I) = * G11.3,* TEST = * G11.3, * XN = * G11.3 ,/
F     3,20X,* XO = * G11.3, * F = * G11.3, * PF = * G11.3* ER = *G11.3)
F      CALL ABNORML
F37    ROE(I) = XXX
 40    CONTINUE
C
C   CONVERT TEMPS BACK TO DEG K
C
       DO 50 I = 2, NTY
F      TX(I) = TX(I)/1.8
 50    CONTINUE
F      RETURN
F      END
F      SUBROUTINE DENSITY(P,TX,ROE)
C
C   THIS SUBROUTINE COMPUTES A DENSITY FOR THE TEMPERATURE TX
C   FOR PRESSURE P
C   P----PRESSURE IN ATMOSPHERES
C   TX---TEMPERATURE IN DEG K
C   ROE--CALCULATED DENSITY IN LBM/CU FT
C
C   THE METHOD WAS DEVELOPED BY R.K. MCMORTIE 1/6/77
C   THE VAN DER WALL EQUATION IS USED FOR A FIRST ESTIMATE OF
C   DENSITY. NEWTON,S METHOD IS THEN USED TO SOLVE FOR THE DENSITY
C   AS A FUNCTION OF BOTH TEMP AND PRESSURE UNTIL A TOLERRANCE OF EPS
C   AN ERROR CORRECTION PARAMETER IS THEN APPLIED TO THE ITERATIVE ANS.
C
       EPS = .00001                 $ CONVERGENCE TOLERANCE
C
C   CONVERT TEMP,S. TO DEG R
C
       TX = TX*1.8            $ DEG R
C
C   BASE A FIRST OF ROE ON V/I DER WALL,S EQUATION
C
       ROE = 2.762*(P/TX)     , ROE VDW
C
C   EVALUATE THE ERROR CORRECTION PARAMETER (FUNCTION OF P ONLY)
C
       ER3 = 1.-EXP(-(P/20.)**4.) $ ERROR COR.
C
C   EVALUATE THE FUNCTION (F) AND THE PARTIAL OF F WITH RESPECT TO
C   ROE (PF) AS A FUNCTION OF TEMP. FOR USE IN NEWTON,S METHOD
C
       LOOP = 1                     $ INITIALIZE ITERATION COUNTER
       XO = ROE
       XA = 0.06472*P + 0.11049*TX
       ER1 = 0.2*EXP(-(TX/1.05)**5.96)
       ER2 = (0.00138*P-0.06944)*(2000./((TX-126.)**2+2000.))
       ER = (ER1+ER2)*ER3
 25    XO2 = XO**2
       F = XO**3.-4.721*XO2+XO*XA-0.30555*P
       PF = 3.*XO2 - 9.442*XO + XA
       XN = XO - (F/PF)              $ NEWTONS METHOD
       TEST = XN-XO
       IF(ABS(TEST).LE.EPS) GO TO 35 $ METHOD CONVERGED
C
C   NO CONVERGENCE CHECK LOOPS AND REITERATE
C
       IF(LOOP.GT.10) GO TO 30      $ NO SOLUTION
       LOOP = LOOP + 1
       XO = XN
       GO TO 25
 30    CONTINUE
       WRITE(6,1001) LOOP, P, TX, ROE, TEST, XN, XO, F, PF, ER
F1001  FORMAT(//20X,*DENSITY FAILED TO CONVERGE AFTER*,I5,*LOOPS* /
F     1,20X,* P = *,G11.5, * TX = * G11.5
F     2,* ROE = * G11.5,* TEST = * G11.5, * XN = * G11.5,/
F     3,20X,* XO = *G11.5* F = *G11.5 * PF = * G11.5* ER = *G11.5)
 35    ROE = XN/(1.-ER)         $ ERROR CORRECTION APPLIED
C
C   CONVERT TEMPS BACK TO DEG K
C
       TX = TX/1.8            $ DEG K
F      RETURN
F      END
F      SUBROUTINE COMPRES
FCALL COMMON
C
C   THIS SUBROUTINE CALCULATES THE OUTLET PRESSURE, FLOW RATE,
C   COMPRESSOR WORK AND FOR NOW IT ASSUMES AN OUTLET TEMPERATURE.
C   IT ULTILIZES THE INLET PRESSURE AND TEMPERATURE AND ALSO THE
C   MECHANICAL EFFICIENCY.
C
C   R1100-----MASS FLOW RATE                        LBM/HR   (CALCULATED)
C   R1101-----MAX. RECOMMENDED CYLINDER TEMP.       DEG F    (INPUT)
C   R1102-----COOLING WATER INLET TEMP              DEG F    (INPUT)
C   R1103-----DT BETWEEN GH2 OUT AND COOLING H2O    DEG F    (INPUT)
C   R1104-----COMPRESSOR OUTLET TEMP.               DEG F    (INPUT)
C   R1105-----COMPRESSOR MECHANICAL EFFICIENCY               (INPUT)
C   R1106-----GH2 DENSITY AT INLET CONDITONS     LBM/CU FT (CALCULATED)
C   R1107-----COMPRESSOR POWER CONSUMPTION          KW       (CALCULATED)
C   R1108-----DIFFERENT FACTOR FOR 3/4 STAGE                 (INPUT)
C   R1109-----DIFFERENT FACTOR FOR 3/4 STAGE                 (INPUT)
C   T1305-----COMPRESSOR OUTLET PRESSURE          ATM,S      (CALCULATED)
C   T305 -----COMPRESSOR OUTLET TEMPERATURE       DEG K      (CALCULATED)
C   T1405-----COMPRESSOR INLET PRESSURE           ATM,S      (INPUT)
C   T405 -----COMPRESSOR INLET TEMPERATURE        DEG K      (INPUT)
C   TT405 ----FICTIOUS COMPRESSOR INLET      300 DEG K      (INPUT)
C
       TT405 = 300.0
       FAC1 = ((R1101+460.)/(TT405*1.8))**3.494
       FAC2 = ((R1101+460.)/((R1102+460.) + R1103))**R1108
       T1305 = R1109*T1405*FAC1*FAC2
       T305 = (R1104 + 460.0)/1.8
C      R1106 = T1405*14.7*144./(R1002*TT405*1.8) $ LBM/CU FT
       R1106 = T1405*14.7*144./(R1002*300.*1.8) $ LBM/CU FT
       R1100 = R1106*R1*60.0        $ MASS FLOW  LBM/HR
       R1107 = 0.06052*(R1100/60.)
       R1107=R1107*(4.*(R1101+460.)-(TT405*1.8)-3.*((TT405*1.8)+R1103))
```

```
       R1107 = R1107/R1105          $ POWER IN KW
F      RETURN
F      END
F      SUBROUTINE DEGFTOK
FCALL COMMON
C
C   THIS SUBROUTINE CONVERTS DEG F TO DEG K FROM RELATIVE NODE ND(1)
C   TO ND(NDUM-1)
C
       IT = NDUM-1                  $ REL NODE NO. TO STOP CONVERT
       DO 10 I = 1, IT
F      T(I) = (T(I)+460.)/1.8
 10    CONTINUE
F      RETURN
F      END
F      SUBROUTINE DEGKTOF
FCALL COMMON
C
C   THIS SUBROUTINE CONVERTS DEG K TO DEG F FROM RELATIVE NODE ND(1)
C   TO ND(NDUM-1)
C
       IT = NDUM-1                  $ REL NODE NO. TO STOP CONVERT
       DO 10 I = 1, IT
F      T(I) = T(I)*1.8 - 460.
 10    CONTINUE
F      RETURN
F      END
F      SUBROUTINE YEILD
FCALL COMMON
       DEGFTOK                              $ NEEDED WHEN CALLED FROM V2
C
C   THIS SUBROUTINE CALCULATES THE YEILD(1175) AND THE JT VALVE
C   OUTLET TEMPERATURE T310 IN DEG K. IT USES THE SATURATION ENTHALPIES
C   AT PRESSURE T1310(OUTLET OF JT VALVE) AND THE ENTHALPY AT
C   H.P. T442 (INLET TO JT VALVE). THE JT OUTLET TEMPERATURE IS THE
C   SATURATION LIQUID TEMPERATURE AT PRESSURE (T1310)
C
       D1DEG1(T1310,A560,R1171)         $ H OF SAT VAPOR
       D1DEG1(T1310,A550,R1172)         $ H OF SAT LIQUID
C   FIND H AT INLET TO JT VALVE, T442, P(T1442) H.P.
       BVSPDA(T1442,A100,A201)          $ H.P. H = F(T) ARRAY
       D1DEG1(T442,A201,R1173)          $ H AT JT VALVE
C   FIND THE QUALITY = (HJT-H SATLIQ)/(H SATVAP-H SATLIQ)
       R1174 = (R1173-R1172)/(R1171-R1172) $ VAPOR FRACTION
C   FIND CONDENSED LIQUID FLOW RATE (LBM/HR) YEILD
       R1175 = (1.-R1174)*R1100*40.63  $ YEILD RATE (GAL/DAY)
C   FIND THE JT VALVE OUTLET TEMPERATURE = SAT. LIQ. TEMP AT R1172
       IF(K1009.NE.0) GO TO 15
       SWITCH(A500,A501)                $ ARRAY OF T=F(H) FROM H=F(T)
       K1009 = 1
 15    D1DEG1(R1172,A501,T310)          $ JT VALVE OUTLET TEMP K
C
C   CALCULATE COMPRESSOR WATER FLOW RATE BASED ON CMAX = CMIN/.2
C   AND OTHER PARAMETERS TO CHECK ON SOLUTION
C
      D1DEG1(T500,A201,R3002)    $ H AT H.P. INLET TO HX1
      BVSPDA(T1699,A100,A201)    $ L.P. H = F(T) ARRAY
      D1DEG1(T699,A201,R3003)    $ H AT L.P. OUTLET OF HX1
       R3004 = R1100*(R3002-R1173)/(R1100*(1.+R1110)*(R3003-R1171))-1.
       R3004 = R3004*100.        $% ENERGY BALANCE ON HX1
       R3005 = R1100*(R3003-R3002)+R1100*R1110*(R3003-R1171)
       R3005 = 40.63*R3005/(R1171-R1172)    $ LIQ.YEILD BASED ON P5/7
       D1DEG1(T500,A201,R1152)              $ MAX POSSIBLE H AT OUTLET
```

```
      R1153 = R1100*((R3002-R1173)+(1.+R1110)*(R3003-R1171))
      R1153 = R1153*1.8/2.0                       $ AVG ACT. Q HX1
      R1154 = R1100*(1.+R1110)*1.8*(R1152-R1171) $ MAX POSS. Q
      R1155 = (R1153/R1154)*100.                 $ EFFICIENCY HX1
      R1177 = 2.88*R1100*3.400/0.2               $ WATER FLOW (GAL/DAY)
      DEGKTOF                                 $ NEEDED WHEN CALLED FROM V2
F     RETURN
F     END
F     SUBROUTINE MNPFIT (N,X,Y,TOL,LAST,SSW1,SSW3,COEF,ISUCCES,NFIT)
C
C     LEAST SQUARES CURVE FIT ROUTINE FROM CDC
C
C     SSW 1  CONTROLS THE OUTPUT OF  NORD,TOL,S2,N,A(I,KK),J
C         ON = PRINTS ONLY WHEN THE TOLERANCE OR HIGHEST ORDER IS SATISF
C         OFF = PRINTS FOR EACH ORDER.
C     SSW 3  CONTROLS THE OUTPUT OF  X(I),Y(I),S1,S3
C         ON = PRINTS ONLY WHEN THE TOLERANCE OR HIGHEST ORDER IS SATISF
C         OFF = PRINTS FOR EACH ORDER.
C     N = NUMBER OF X(I) AND Y(I) POINTS INPUT
C     TOL = TOLERANCE TO WHICH THE CURVE IS TO BE FIT.
C     LAST = HIGHEST ORDER YOU WANT FIT (15 IS THE MAXIMUM).
C     NORD = ORDER THAT IS PRESENTLY BEING CALCULATED.
C     L = NORD+1
C     KK = NORD+2
C     S1 = NEW Y(I)
C     S2 = STANDARD DEVIATION
C     S3 = DIFFERENCE BETWEEN THE OLD AND NEW Y(I)
C     NFIT IS A FLAG WHICH IF NON-ZERO AND PROGRAM TERMINATES WITHOUT
C     FINDING A FIT WITHIN TOLERANCE, GOES BACK AND RECALCULATES
C     COEFFICIENTS FOR THE ORDER WITH THE BEST TOLERANCE
C     ISUCCES IF ZERO, THEN PROGRAM WAS NOT SUCCESSFUL IN FITTING TOLERA
C
C
F     DIMENSION COEF(1), G(2,15)
F     DIMENSION X(1), Y(1), A(16,16), SUMX(31), SUMY(16)
C     PRINT 2300
C
F     IF (LAST.GT.N-1.OR.LAST.GT.15) PRINT 2400
F     FLAST          =LAST
F     NOFT           =0
F     SUMX(1)        =N
F     SUMX(2)        =0.
F     SUMX(3)        =0.
F     SUMY(1)        =0.
F     SUMY(2)        =0.
F     DO 100 I=1,N
F     SUMX(2)        =SUMX(2)+X(I)
F     SUMX(3)        =SUMX(3)+X(I)**2
F     SUMY(1)        =SUMY(1)+Y(I)
F     SUMY(2)        =SUMY(2)+X(I)*Y(I)
100   CONTINUE
F     NORD           =1
F     GO TO 400
200   CONTINUE
F     NORD           =NORD+1
F     J              =2*NORD
F     SUMX(J)        =0.
F     SUMX(J+1)      =0.
F     SUMY(NORD+1)   =0.
F     DO 300 I=1,N
F     SUMX(J)        =SUMX(J)+X(I)**(J-1)
F     SUMX(J+1)      =SUMX(J+1)+X(I)**J
F     SUMY(NORD+1)   =SUMY(NORD+1)+Y(I)*X(I)**NORD
```

```
300   CONTINUE
400   CONTINUE
F     L              =NORD+1
F     KK             =NORD+2
F     DO 600 I=1,L
F     DO 500 J=1,L
F     IK             =I+J-1
F     A(I,J)         =SUMX(IK)
500   CONTINUE
F     A(I,KK)        =SUMY(I)
600   CONTINUE
F     DO 900 I=1,L
F     A(KK,I)        =-1.
F     KKK            =I+1
F     DO 700 J=KKK,KK
F     A(KK,J)        =0.
700   CONTINUE
F     CC             =1./A(1,I)
F     DO 800 II=2,KK
F     DO 800 J=KKK,KK
F     A(II,J)        =A(II,J)-A(1,J)*A(II,I)*CC
800   CONTINUE
F     DO 900 II=1,L
F     DO 900 J=KKK,KK
F     A(II,J)        =A(II+1,J)
900   CONTINUE
F     S2             =0.
F     DO 1100 J=1,N
F     S1             =A(1,KK)
F     DO 1000 I=1,NORD
F     S1             =S1+A(I+1,KK)*X(J)**I
1000  CONTINUE
F     S2             =S2+(S1-Y(J))**2
1100  CONTINUE
F     IF (N-L) 1200,1250,1300
1200  CONTINUE
F     PRINT 3100
F     ISUCCES        =0
F     RETURN
F1250 S2 = 0.0
F     GOTO 1350
1300  CONTINUE
F     B              =N-L
F     S2             =(S2/B)**.5
F1350 FNORD = NORD
F     G(1,NORD)      =NORD
F     G(2,NORD)      =S2
F     CHECK          =(FNORD-FLAST)*(S2-TOL)
F     IF (SSW1.NE.0.)              GO TO 1400
F     IF (CHECK)                   1600,1400,1400
1400  CONTINUE
F     PRINT 2500
F     PRINT 2600, NORD,TOL,S2,N,LAST
F     PFLG           =0.0
F     PRINT 2900
F     DO 1500 I=1,L
F     J              =I-1
F     PRINT 3000, J,A(I,KK)
F     COEF(I)        =A(I,KK)
1500  CONTINUE
F     ISUCCES        =L
1600  CONTINUE
F     IF (SSW3.NE.0.)              GO TO 1700
F     IF (CHECK)                         200,1700,1700
1700  CONTINUE
F     DO 1900 I=1,N
F     S1             =A(1,KK)
F     DO 1800 J=1,NORD
F     S1             =S1+A(J+1,KK)*X(I)**J
1800  CONTINUE
F     S3             =Y(I)-S1
C     IF (PFLG.EQ.0.0)                   PRINT 2700
F     PFLG           =1.0
C     PRINT 2300, X(I),Y(I),S1,S3
1900  CONTINUE
F     IF (CHECK)                         200,2000,2000
2000  CONTINUE
F     IF (NORD.GE.LAST.AND.S2.GT.TOL) GO TO 2100
F     RETURN
2100  CONTINUE
F     PRINT 3200
F     ISUCCES        =0
F     IF (NFIT.EQ.0.OR.NBFT.NE.0) RETURN
F     NBFT           =1
F     NORDM          =NORD-1
F     SMALL          =G(2,1)
F     DO 2200 I=1,NORDM
F     IF (G(2,I+1).GT.SMALL)        GO TO 2200
F     SMALL          =G(2,I+1)
F     NBFT           =I+1
2200  CONTINUE
F     TOL            =G(2,NBFT)+0.000001
F     NORD           =NBFT-1
F     GO TO 200
C
C
C
F2300 FORMAT (1H1)
F2400 FORMAT (/////42HW A R N I N G - ORDER LIMIT IS TOO LARGE. )
F2500 FORMAT (1H1,15X,14HCURRENT ORDER ,09X,10HTOLERANCE ,13X,19HSTANDAR
F    1D DEVIATION ,7X,17HNUMBER OF POINTS ,5X,18HMAXIMUM REQUESTED )
F2600 FORMAT (21X,I2,13XE15.8,12XE15.8,14XI5,20XI2)
F2700 FORMAT (///21X,1HX,28X,1HY,27X,2HYP,27X,2HYD/)
F2800 FORMAT (/4(14XE15.8))
F2900 FORMAT (//20X,5HORDER,20X,11HCOEFFICIENT)
F3000 FORMAT (1H0,19X,I3,20X,E15.8)
F3100 FORMAT (35HORDER IS GREATER THAN NO. OF POINTS)
F3200 FORMAT (45H REACHED LAST BEFORE FIT WAS WITHIN TOLERANCE)
F     END
      END                               $ END OF SUBROUTINE BLOCK
      BCD 3END OF DATA
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APPENDIX D

Detailed Life-Cycle Cost Data Sheets For 132 Combinations and Variations of Conditions

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The life cycle costs analysis presented herein was based on a preliminary estimate of capital investment cost made early in the program. The estimate for the selected system (closed loop, LN_2 precooled, two compressor with 25 percent cycle venting) was later refined as presented in Appendix E. The difference in the estimates has very minor effect on the overall economics and the data sheets included herein provide a valid economic comparison of the competitive systems.

LIFE CYCLE COST ------SYSTEM 1 NO VENTING

ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YE.. LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 178249.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 401206.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 0. GAL/LOADING
  - DEWAR LOADING = 0. GAL/LOADING
  - TOTAL = 80901.8 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 5.8%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW ------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
	$ 632151.2	$ 111855.0	$ 1145212.2	$ 2123672.9	$ 978460.7

PAY BACK OCCURS DURING YEAR 4

NET SAVINGS OVER 15 YEARS = .978 MILLION DOLLARS

-------------- IN 15 YEARS --------------
- TOTAL H2 SAVED WITH SYSTEM = 1.214 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
- TOTAL NITROGEN EXPENDED = 2.524 MILLION LBS
- TOTAL WATER EXPENDED = 8.624 MILLION GALS
- TOTAL POWER EXPENDED = 5.758 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST               OPERATING COST
  EQUIP AND MATL= $  178249.00          LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00          LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00          POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00          LN2 RATE  =  .041 $/LB
                   -----------          WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                 SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK              HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                  NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR              SHUTTLE LAUNCH =  161.8 GAL/LOADING
                                          DEWAR LOADING  =  692.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR             TOTAL          =  90956.0 LB/YEAR
  OPERATING LABOR=  6.00                LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00              OPERATIONAL PARAMETERS
  POWER          = 10.00                PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00                NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20203.1	$ 4805.6	$ 426214.7	$ 159173.0	$ -267041.6
2	$ 22016.8	$ 5093.9	$ 27110.7	$ 159173.0	$ 132062.3
3	$ 23999.5	$ 5399.6	$ 29399.1	$ 159173.0	$ 129773.9
4	$ 26167.4	$ 5723.5	$ 31890.9	$ 159173.0	$ 127282.1
5	$ 28538.1	$ 6067.0	$ 34605.0	$ 159173.0	$ 124568.0
6	$ 31131.1	$ 6431.0	$ 37562.0	$ 159173.0	$ 121611.0
7	$ 33967.7	$ 6816.8	$ 40784.6	$ 159173.0	$ 118388.5
8	$ 37071.5	$ 7225.8	$ 44297.3	$ 159173.0	$ 114875.7
9	$ 40468.0	$ 7659.4	$ 48127.4	$ 159173.0	$ 111045.7
10	$ 44185.5	$ 8119.0	$ 52304.5	$ 159173.0	$ 106868.6
11	$ 48255.1	$ 8606.1	$ 56861.2	$ 159173.0	$ 102311.9
12	$ 52710.6	$ 9122.5	$ 61833.1	$ 159173.0	$ 97340.0
13	$ 57589.5	$ 9669.8	$ 67259.3	$ 159173.0	$ 91913.7
14	$ 62932.8	$ 10250.0	$ 73182.8	$ 159173.0	$ 85990.2
15	$ 68785.5	$ 10865.0	$ 79650.5	$ 159173.0	$ 79522.6
	$ 598022.0	$ 111855.0	$ 1111083.0	$ 2387595.6	$ 1276512.6

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = 1.277 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.364 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .123 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.131 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST		OPERATING COST	
EQUIP AND MATL=	$ 178249.00	LABOR TIME=	8.0 HR/WEEK
DETAILED DESIGN=	$ 47134.00	LABOR RATE=	12.00 $/HR
FABRICATION =	$ 123940.00	POWER RATE=	.024 $/KW-HR
INSTALLATION =	$ 51883.00	LN2 RATE =	.041 $/LB
	-----------	WATER RATE=	.0003 $/GAL
TOTAL * (1.00)	$ 401206.00		

MAINTENANCE COST DATA		SAVINGS DATA	
LABOR TIME=	6.9 HR/WEEK	HYDROGEN RELIQUEFIED	
LABOR RATE=	12.00 $/HR	NORMAL BOILOFF =	400.0 GAL/DAY
MATERIALS =	500.00 $/YEAR	SHUTTLE LAUNCH =	297.6 GAL/LOADING
		DEWAR LOADING =	1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR		TOTAL =	99424.3 LB/YEAR
OPERATING LABOR=	6.00	LIQ HYDROGEN COST=	1.75 $/LB
MAINTEN. LABOR =	6.00		
MAINTEN. MATL =	6.00	OPERATIONAL PARAMETERS	
POWER =	10.00	PERCENT DOWN TIME =	5.8%
LIQ NITROGEN =	10.00	NO. OF SHUTTLE LAUNCHES/YEAR=	20.0
WATER =	6.00	NO. OF DEWAR LOADINGS/YR =	20.0
LIQ. HYDROGEN =	0.		

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19576.2	$ 4805.6	$ 425587.8	$ 173992.6	$ -251595.2
2	$ 21327.2	$ 5093.9	$ 26421.1	$ 173992.6	$ 147571.4
3	$ 23240.9	$ 5399.6	$ 28640.5	$ 173992.6	$ 145352.1
4	$ 25332.9	$ 5723.5	$ 31056.5	$ 173992.6	$ 142936.1
5	$ 27620.2	$ 6067.0	$ 33687.1	$ 173992.6	$ 140305.4
6	$ 30121.4	$ 6431.0	$ 36552.4	$ 173992.6	$ 137440.2
7	$ 32857.1	$ 6816.8	$ 39673.9	$ 173992.6	$ 1343[illegible].7
8	$ 35849.7	$ 7225.8	$ 43075.6	$ 173992.6	$ 130917.0
9	$ 39124.1	$ 7659.4	$ 46783.5	$ 173992.6	$ 1272[illegible].1
10	$ 42707.3	$ 8119.0	$ 50826.2	$ 173992.6	$ 123166.3
11	$ 46629.0	$ 8606.1	$ 55235.1	$ 173992.6	$ 118757.5
12	$ 50921.9	$ 9122.5	$ 60044.4	$ 173992.6	$ 113948.2
13	$ 55622.0	$ 9669.8	$ 65291.8	$ 173992.6	$ 108700.8
14	$ 60768.5	$ 10250.0	$ 71018.5	$ 173992.6	$ 102974.1
15	$ 66404.7	$ 10865.0	$ 77269.7	$ 173992.6	$ 96722.9
	$ 578103.0	$ 111855.0	$ 1091164.0	$ 2609888.5	$ 1518724.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.519 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM	=	1.491 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	=	6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	=	.246 MILLION LBS
TOTAL NITROGEN EXPENDED	=	1.902 MILLION LBS
TOTAL WATER EXPENDED	=	8.624 MILLION GALS
TOTAL POWER EXPENDED	=	5.758 MILLION KW-HR

```
    -- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
  ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  178249.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                    -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  654.8 GAL/LOADING
                                       DEWAR LOADING  = 2769.6 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  121189.2 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 18758.3	$ 4805.6	$ 424769.9	$ 212081.1	$ -212688.8
2	$ 20427.5	$ 5093.9	$ 25521.5	$ 212081.1	$ 186559.6
3	$ 22251.3	$ 5399.6	$ 27650.9	$ 212081.1	$ 184430.2
4	$ 24244.3	$ 5723.5	$ 29967.9	$ 212081.1	$ 182113.2
5	$ 26422.7	$ 6067.0	$ 32489.7	$ 212081.1	$ 179591.4
6	$ 28804.2	$ 6431.0	$ 35235.2	$ 212081.1	$ 176845.9
7	$ 31408.2	$ 6816.8	$ 38225.0	$ 212081.1	$ 173856.1
8	$ 34256.0	$ 7225.8	$ 41481.8	$ 212081.1	$ 170599.3
9	$ 37370.9	$ 7659.4	$ 45030.3	$ 212081.1	$ 167050.8
10	$ 40778.8	$ 8119.0	$ 48897.7	$ 212081.1	$ 163183.4
11	$ 44507.7	$ 8606.1	$ 53113.8	$ 212081.1	$ 158967.4
12	$ 48588.5	$ 9122.5	$ 57710.9	$ 212081.1	$ 154370.2
13	$ 53055.2	$ 9669.8	$ 62725.0	$ 212081.1	$ 149356.1
14	$ 57945.0	$ 10250.0	$ 68195.0	$ 212081.1	$ 143886.1
15	$ 63298.9	$ 10865.0	$ 74163.9	$ 212081.1	$ 137917.2
	$ 552117.5	$ 111855.0	$ 1065178.5	$ 3181216.6	$ 2116038.1

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 2.116 MILLION DOLLARS

-------------- IN 15 YEARS -----------------
TOTAL H2 SAVED WITH SYSTEM     =  1.818 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =   .615 MILLION LBS
TOTAL NITROGEN EXPENDED        =  1.603 MILLION LBS
TOTAL WATER EXPENDED           =  8.624 MILLION GALS
TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST

EQUIP AND MATL=	$ 275821.00
DETAILED DESIGN=	$ 47134.00
FABRICATION =	$ 123940.00
INSTALLATION =	$ 51883.00
TOTAL * (1.00)	$ 498778.00

OPERATING COST

LABOR TIME=	8.0 HR/WEEK
LABOR RATE=	12.00 $/HR
POWER RATE=	.024 $/KW-HR
LN2 RATE =	.041 $/LB
WATER RATE=	.0003 $/GAL

MAINTENANCE COST DATA

LABOR TIME=	6.9 HR/WEEK
LABOR RATE=	12.00 $/HR
MATERIALS =	500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED

NORMAL BOILOFF =	400.0 GAL/DAY
SHUTTLE LAUNCH =	747.0 GAL/LOADING
DEWAR LOADING =	2988.0 GAL/LOADING
TOTAL =	128965.7 LB/YEAR
LIQ HYDROGEN COST=	1.75 $/LB

ESCALATION RATES, PERCENT/YEAR

OPERATING LABOR=	6.00
MAINTEN. LABOR =	6.00
MAINTEN. MATL =	6.00
POWER =	10.00
LIQ NITROGEN =	10.00
WATER =	6.00
LIQ. HYDROGEN =	0.

OPERATIONAL PARAMETERS

PERCENT DOWN TIME =	1.0%
NO. OF SHUTTLE LAUNCHES/YEAR=	20.0
NO. OF DEWAR LOADINGS/YR =	20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32533.4	$ 4805.6	$ 536117.0	$ 225690.0	$ -310427.0
2	$ 35575.8	$ 5093.9	$ 40669.7	$ 225690.0	$ 185020.3
3	$ 38909.8	$ 5399.6	$ 44309.3	$ 225690.0	$ 181380.7
4	$ 42563.7	$ 5723.5	$ 48287.3	$ 225690.0	$ 177402.8
5	$ 46568.9	$ 6067.0	$ 52635.8	$ 225690.0	$ 173054.2
6	$ 50959.4	$ 6431.0	$ 57390.4	$ 225690.0	$ 168299.6
7	$ 55773.1	$ 6816.8	$ 62589.9	$ 225690.0	$ 163100.1
8	$ 61051.2	$ 7225.8	$ 68277.0	$ 225690.0	$ 157413.0
9	$ 66839.1	$ 7659.4	$ 74498.5	$ 225690.0	$ 151191.5
10	$ 73186.8	$ 8119.0	$ 81305.7	$ 225690.0	$ 144384.3
11	$ 80149.1	$ 8606.1	$ 88755.2	$ 225690.0	$ 136934.9
12	$ 87786.2	$ 9122.5	$ 96908.7	$ 225690.0	$ 128781.4
13	$ 96164.4	$ 9669.8	$ 105834.2	$ 225690.0	$ 119855.8
14	$ 105356.4	$ 10250.0	$ 115606.4	$ 225690.0	$ 110083.7
15	$ 115442.1	$ 10865.0	$ 126307.1	$ 225690.0	$ 99383.0
	$ 988859.2	$ 111855.0	$ 1599492.2	$ 3385350.6	$ 1785858.4

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.786 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM =	1.934 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =	6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM =	0. MILLION LBS
TOTAL NITROGEN EXPENDED =	4.471 MILLION LBS
TOTAL WATER EXPENDED =	14.082 MILLION GALS
TOTAL POWER EXPENDED =	9.400 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  275821.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 1095.4 GAL/LOADING
                                         DEWAR LOADING  = 4484.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  150674.1 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR      =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30338.3	$ 4805.6	$ 533921.9	$ 263679.8	$ -270242.1
2	$ 33161.2	$ 5093.9	$ 38255.1	$ 263679.8	$ 225424.6
3	$ 36253.7	$ 5399.6	$ 41653.3	$ 263679.8	$ 222026.5
4	$ 39642.0	$ 5723.5	$ 45365.6	$ 263679.8	$ 218314.2
5	$ 43355.0	$ 6067.0	$ 49422.0	$ 263679.8	$ 214257.8
6	$ 47424.2	$ 6431.0	$ 53855.2	$ 263679.8	$ 209824.6
7	$ 51884.3	$ 6816.8	$ 58701.1	$ 263679.8	$ 204978.6
8	$ 56773.5	$ 7225.8	$ 63999.4	$ 263679.8	$ 199680.4
9	$ 62133.7	$ 7659.4	$ 69793.1	$ 263679.8	$ 1938[illegible].7
10	$ 68010.8	$ 8119.0	$ 76129.8	$ 263679.8	$ 187550.0
11	$ 74455.5	$ 8606.1	$ 83061.6	$ 263679.8	$ 180618.1
12	$ 81523.3	$ 9122.5	$ 90645.8	$ 263679.8	$ 173034.0
13	$ 89275.2	$ 9669.8	$ 98945.0	$ 263679.8	$ 164734.7
14	$ 97778.3	$ 10250.0	$ 108028.3	$ 263679.8	$ 155651.5
15	$ 107106.2	$ 10865.0	$ 117971.2	$ 263679.8	$ 145708.6
	$ 919115.2	$ 111855.0	$ 1529748.2	$ 3955196.3	$ 2425448.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.425 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  2.260 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
TOTAL NITROGEN EXPENDED       =  3.668 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  275821.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                    -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH = 1382.0 GAL/LOADING
                                     DEWAR LOADING  = 5704.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR        TOTAL          =  168389.6 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 28861.9	$ 4805.6	$ 532445.5	$ 294681.8	$ -237763.7
2	$ 31537.1	$ 5093.9	$ 36631.1	$ 294681.8	$ 258050.7
3	$ 34467.3	$ 5399.6	$ 39866.8	$ 294681.8	$ 254814.9
4	$ 37677.0	$ 5723.5	$ 43400.5	$ 294681.8	$ 251281.3
5	$ 41193.4	$ 6067.0	$ 47260.4	$ 294681.8	$ 247421.4
6	$ 45046.4	$ 6431.0	$ 51477.4	$ 294681.8	$ 243204.4
7	$ 49268.8	$ 6816.8	$ 56085.6	$ 294681.8	$ 238590.1
8	$ 53896.4	$ 7225.8	$ 61122.3	$ 294681.8	$ 233559.5
9	$ 58968.9	$ 7659.4	$ 66628.3	$ 294681.8	$ 2280[illegible].5
10	$ 64529.6	$ 8119.0	$ 72648.5	$ 294681.8	$ 222033.2
11	$ 70626.1	$ 8606.1	$ 79232.2	$ 294681.8	$ 215449.5
12	$ 77311.0	$ 9122.5	$ 86433.4	$ 294681.8	$ 208248.3
13	$ 84641.6	$ 9669.8	$ 94311.5	$ 294681.8	$ 200370.3
14	$ 92681.3	$ 10250.0	$ 102931.3	$ 294681.8	$ 191750.4
15	$ 101499.5	$ 10865.0	$ 112364.5	$ 294681.8	$ 182317.2
	$ 872206.5	$ 111855.0	$ 1482839.5	$ 4420226.5	$ 2937387.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.937 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  2.526 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .492 MILLION LBS
TOTAL NITROGEN EXPENDED       =  3.127 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2122.0 GAL/LOADING
DEWAR LOADING = 8848.0 GAL/LOADING
TOTAL = 214084.1 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 26656.8	$ 4805.6	$ 530240.4	$ 374647.1	$ -155593.3
2	$ 29111.6	$ 5093.9	$ 34205.5	$ 374647.1	$ 340441.6
3	$ 31799.1	$ 5399.6	$ 37198.7	$ 374647.1	$ 337448.4
4	$ 34742.0	$ 5723.5	$ 40465.6	$ 374647.1	$ 334181.6
5	$ 37965.0	$ 6067.0	$ 44031.9	$ 374647.1	$ 330615.2
6	$ 41495.2	$ 6431.0	$ 47926.1	$ 374647.1	$ 326721.0
7	$ 45362.4	$ 6816.8	$ 52179.2	$ 374647.1	$ 322467.9
8	$ 49599.4	$ 7225.8	$ 56825.2	$ 374647.1	$ 317821.9
9	$ 54242.1	$ 7659.4	$ 61901.5	$ 374647.1	$ 312745.6
10	$ 59330.1	$ 8119.0	$ 67449.1	$ 374647.1	$ 307198.0
11	$ 64906.8	$ 8606.1	$ 73512.9	$ 374647.1	$ 301134.2
12	$ 71019.7	$ 9122.5	$ 80142.1	$ 374647.1	$ 294505.0
13	$ 77721.2	$ 9669.8	$ 87391.0	$ 374647.1	$ 287256.1
14	$ 85068.9	$ 10250.0	$ 95318.9	$ 374647.1	$ 279328.3
15	$ 93125.8	$ 10865.0	$ 103990.8	$ 374647.1	$ 270656.3
	$ 802146.1	$ 111855.0	$ 1412779.1	$ 5619706.7	$ 4206927.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.207 MILLION DOLLARS

------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.211 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 1.230 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.321 MILLION LBS
TOTAL WATER EXPENDED = 14.082 MILLION GALS
TOTAL POWER EXPENDED = 9.400 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  470965.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 2696.0 GAL/LOADING
                                         DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  243613.7 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 51862.7	$ 4805.6	$ 750590.3	$ 426324.0	$ -324266.3
2	$ 56829.1	$ 5093.9	$ 61923.0	$ 426324.0	$ 364401.0
3	$ 62278.8	$ 5399.6	$ 67678.4	$ 426324.0	$ 358645.6
4	$ 68259.5	$ 5723.5	$ 73983.1	$ 426324.0	$ 352340.9
5	$ 74823.5	$ 6067.0	$ 80890.5	$ 426324.0	$ 345433.5
6	$ 82028.2	$ 6431.0	$ 88459.2	$ 426324.0	$ 337864.8
7	$ 89936.7	$ 6816.8	$ 96753.5	$ 426324.0	$ 329570.5
8	$ 98618.3	$ 7225.8	$ 105844.2	$ 426324.0	$ 320479.8
9	$ 108149.4	$ 7659.4	$ 115808.8	$ 426324.0	$ 310515.2
10	$ 118613.8	$ 8119.0	$ 126732.7	$ 426324.0	$ 299591.3
11	$ 130103.6	$ 8606.1	$ 138709.7	$ 426324.0	$ 287614.3
12	$ 142720.0	$ 9122.5	$ 151842.5	$ 426324.0	$ 274481.5
13	$ 156574.5	$ 9669.8	$ 166244.3	$ 426324.0	$ 260079.7
14	$ 171789.3	$ 10250.0	$ 182039.3	$ 426324.0	$ 244284.7
15	$ 188499.1	$ 10865.0	$ 199364.1	$ 426324.0	$ 226959.9
	$ 1601086.5	$ 111855.0	$ 2406863.5	$ 6394860.0	$ 3987996.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.988 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM     =  3.654 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED        =  7.059 MILLION LBS
TOTAL WATER EXPENDED           = 25.344 MILLION GALS
TOTAL POWER EXPENDED           = 16.919 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 2 5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 3326.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 251025.5 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50954.8	$ 4805.6	$ 749682.4	$ 439294.7	$ -310387.7
2	$ 55830.3	$ 5093.9	$ 60924.3	$ 439294.7	$ 378370.4
3	$ 61180.2	$ 5399.6	$ 66579.8	$ 439294.7	$ 372714.9
4	$ 67051.1	$ 5723.5	$ 72774.7	$ 439294.7	$ 366520.0
5	$ 73494.2	$ 6067.0	$ 79561.2	$ 439294.7	$ 359733.5
6	$ 80566.0	$ 6431.0	$ 86997.0	$ 439294.7	$ 352297.7
7	$ 88328.2	$ 6816.8	$ 95145.1	$ 439294.7	$ 344149.6
8	$ 96849.0	$ 7225.8	$ 104074.9	$ 439294.7	$ 335219.8
9	$ 106203.2	$ 7659.4	$ 113862.6	$ 439294.7	$ 3254[illegible].1
10	$ 116473.0	$ 8119.0	$ 124591.9	$ 439294.7	$ 314702.8
11	$ 127748.7	$ 8606.1	$ 136354.7	$ 439294.7	$ 302939.9
12	$ 140129.6	$ 9122.5	$ 149252.1	$ 439294.7	$ 290042.6
13	$ 153725.0	$ 9669.8	$ 163394.8	$ 439294.7	$ 275899.8
14	$ 168654.9	$ 10250.0	$ 178904.9	$ 439294.7	$ 260389.8
15	$ 185051.3	$ 10865.0	$ 195916.3	$ 439294.7	$ 243378.4
	$ 1572239.7	$ 111855.0	$ 2378016.7	$ 6589420.4	$ 4211403.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.211 MILLION DOLLARS

------------- IN 15 YEARS -----------------
TOTAL H2 SAVED WITH SYSTEM = 3.765 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .104 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.727 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

```
-- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST                 OPERATING COST
  EQUIP AND MATL= $  470965.00            LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00            LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00            POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00            LN2 RATE   =  .041 $/LB
                     -----------          WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                   SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK                HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                    NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR                SHUTTLE LAUNCH = 3884.0 GAL/LOADING
                                            DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR               TOTAL          =  257590.3 LB/YEAR
  OPERATING LABOR=  6.00                  LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00                OPERATIONAL PARAMETERS
  POWER          = 10.00                  PERCENT DOWN TIME               =  1.0%
  LIQ NITROGEN   = 10.00                  NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                  NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW ---------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  693922.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50476.8	$ 4805.6	$ 749204.4	$ 450783.0	$ -298421.4
2	$ 55304.6	$ 5093.9	$ 60398.5	$ 450783.0	$ 390384.5
3	$ 60601.9	$ 5399.6	$ 66001.4	$ 450783.0	$ 384781.6
4	$ 66414.9	$ 5723.5	$ 72138.5	$ 450783.0	$ 378644.6
5	$ 72794.4	$ 6067.0	$ 78861.4	$ 450783.0	$ 371921.6
6	$ 79796.2	$ 6431.0	$ 86227.2	$ 450783.0	$ 364555.9
7	$ 87481.4	$ 6816.8	$ 94298.3	$ 450783.0	$ 35648[illegible].7
8	$ 95917.6	$ 7225.8	$ 103143.4	$ 450783.0	$ 347639.6
9	$ 105178.6	$ 7659.4	$ 112838.0	$ 450783.0	$ 3379[illegible]5.0
10	$ 115345.9	$ 8119.0	$ 123464.9	$ 450783.0	$ 327318.2
11	$ 126508.9	$ 8606.1	$ 135115.0	$ 450783.0	$ 315668.0
12	$ 138765.9	$ 9122.5	$ 147888.3	$ 450783.0	$ 302894.7
13	$ 152224.9	$ 9669.8	$ 161894.7	$ 450783.0	$ 288888.3
14	$ 167004.8	$ 10250.0	$ 177254.8	$ 450783.0	$ 273528.2
15	$ 183236.1	$ 10865.0	$ 194101.1	$ 450783.0	$ 256681.9
	$ 1557052.9	$ 111855.0	$ 2362829.9	$ 6761745.3	$ 4398915.4

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 4.399 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.864 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .209 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.552 MILLION LBS
TOTAL WATER EXPENDED          = 25.344 MILLION GALS
TOTAL POWER EXPENDED          = 16.919 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 5374.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 275119.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 49893.2	$ 4805.6	$ 748620.8	$ 481459.7	$ -267161.1
2	$ 54662.6	$ 5093.9	$ 59756.5	$ 481459.7	$ 421703.2
3	$ 59895.7	$ 5399.6	$ 65295.2	$ 481459.7	$ 416164.5
4	$ 65638.1	$ 5723.5	$ 71361.6	$ 481459.7	$ 410098.1
5	$ 71939.9	$ 6067.0	$ 78006.9	$ 481459.7	$ 403452.8
6	$ 78856.2	$ 6431.0	$ 85287.2	$ 481459.7	$ 396172.5
7	$ 86447.5	$ 6816.8	$ 93264.3	$ 481459.7	$ 388195.4
8	$ 94780.3	$ 7225.8	$ 102006.1	$ 481459.7	$ 379453.6
9	$ 103927.5	$ 7659.4	$ 111586.9	$ 481459.7	$ 369872.8
10	$ 113969.7	$ 8119.0	$ 122088.7	$ 481459.7	$ 359371.0
11	$ 124995.1	$ 8606.1	$ 133601.2	$ 481459.7	$ 347858.5
12	$ 137100.7	$ 9122.5	$ 146223.2	$ 481459.7	$ 335236.6
13	$ 150393.2	$ 9669.8	$ 160063.0	$ 481459.7	$ 321396.7
14	$ 164989.9	$ 10250.0	$ 175239.9	$ 481459.7	$ 306219.8
15	$ 181019.8	$ 10865.0	$ 191884.8	$ 481459.7	$ 289574.9
	$ 1538509.5	$ 111855.0	$ 2344286.5	$ 7221896.0	$ 4877609.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.878 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 4.127 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .522 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.338 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
ONE COMPRESSOR, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  178249.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE   =  .041 $/LB
                  -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =     0.  GAL/LOADING
                                       DEWAR LOADING  =     0.  GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  80901.8 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
	$ 632151.2	$ 111855.0	$ 1145212.2	$ 2123672.9	$ 978460.7

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = .978 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.214 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.524 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE   =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =   500.00 $/YEAR            SHUTTLE LAUNCH =   80.9 GAL/LOADING
                                         DEWAR LOADING  =  692.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          = 90004.2 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20310.7	$ 4805.6	$ 426322.3	$ 157507.4	$ -268814.8
2	$ 22135.2	$ 5093.9	$ 27229.1	$ 157507.4	$ 130278.3
3	$ 24129.7	$ 5399.6	$ 29529.3	$ 157507.4	$ 127978.2
4	$ 26310.6	$ 5723.5	$ 32034.1	$ 157507.4	$ 125473.3
5	$ 28695.6	$ 6067.0	$ 34762.5	$ 157507.4	$ 122744.9
6	$ 31304.3	$ 6431.0	$ 37735.3	$ 157507.4	$ 119772.1
7	$ 34158.3	$ 6816.8	$ 40975.2	$ 157507.4	$ 116532.3
8	$ 37281.1	$ 7225.8	$ 44507.0	$ 157507.4	$ 113000.5
9	$ 40698.6	$ 7659.4	$ 48358.0	$ 157507.4	$ 109149.4
10	$ 44439.2	$ 8119.0	$ 52558.2	$ 157507.4	$ 104949.3
11	$ 48534.1	$ 8606.1	$ 57140.2	$ 157507.4	$ 100367.2
12	$ 53017.6	$ 9122.5	$ 62140.0	$ 157507.4	$ 95367.4
13	$ 57927.2	$ 9669.8	$ 67597.0	$ 157507.4	$ 89910.4
14	$ 63304.2	$ 10250.0	$ 73554.2	$ 157507.4	$ 83953.2
15	$ 69194.0	$ 10865.0	$ 80059.0	$ 157507.4	$ 77448.4
	$ 601440.4	$ 111855.0	$ 1114501.4	$ 2362611.5	$ 1248110.1

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = 1.248 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.350 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .111 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.171 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =   500.00 $/YEAR            SHUTTLE LAUNCH =  148.8 GAL/LOADING
                                         DEWAR LOADING  = 1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  97673.7 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME            =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     = 20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19746.1	$ 4805.6	$ 425757.7	$ 170929.0	$ -254828.7
2	$ 21514.1	$ 5093.9	$ 26608.1	$ 170929.0	$ 144321.0
3	$ 23446.6	$ 5399.6	$ 28846.1	$ 170929.0	$ 142082.9
4	$ 25559.1	$ 5723.5	$ 31282.7	$ 170929.0	$ 139646.4
5	$ 27869.0	$ 6067.0	$ 33935.9	$ 170929.0	$ 136993.1
6	$ 30395.1	$ 6431.0	$ 36826.0	$ 170929.0	$ 134103.0
7	$ 33158.1	$ 6816.8	$ 39975.0	$ 170929.0	$ 130954.0
8	$ 36180.9	$ 7225.8	$ 43406.8	$ 170929.0	$ 127522.3
9	$ 39488.4	$ 7659.4	$ 47147.8	$ 170929.0	$ 123781.2
10	$ 43108.0	$ 8119.0	$ 51226.9	$ 170929.0	$ 119702.1
11	$ 47069.7	$ 8606.1	$ 55675.8	$ 170929.0	$ 115253.2
12	$ 51406.8	$ 9122.5	$ 60529.2	$ 170929.0	$ 110399.8
13	$ 56155.3	$ 9669.8	$ 65825.1	$ 170929.0	$ 105103.9
14	$ 61355.2	$ 10250.0	$ 71605.2	$ 170929.0	$ 99323.9
15	$ 67050.1	$ 10865.0	$ 77915.1	$ 170929.0	$ 93014.0
	$ 583502.3	$ 111855.0	$ 1096563.3	$ 2563935.2	$ 1467371.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.467 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

```
TOTAL H2 SAVED WITH SYSTEM     =  1.465 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =   .221 MILLION LBS
TOTAL NITROGEN EXPENDED        =  1.964 MILLION LBS
TOTAL WATER EXPENDED           =  8.624 MILLION GALS
TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  178249.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                   -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  327.4 GAL/LOADING
                                       DEWAR LOADING  = 2769.6 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          = 117337.4 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME             =  5.8%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR      =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19008.1	$ 4805.6	$ 425019.7	$ 205340.5	$ -219679.2
2	$ 20702.3	$ 5093.9	$ 25796.3	$ 205340.5	$ 179544.2
3	$ 22553.6	$ 5399.6	$ 27953.2	$ 205340.5	$ 177387.3
4	$ 24576.9	$ 5723.5	$ 30300.4	$ 205340.5	$ 175040.1
5	$ 26788.5	$ 6067.0	$ 32855.5	$ 205340.5	$ 172485.0
6	$ 29206.5	$ 6431.0	$ 35637.5	$ 205340.5	$ 169702.9
7	$ 31950.8	$ 6816.8	$ 38667.6	$ 205340.5	$ 166672.9
8	$ 34742.8	$ 7225.8	$ 41968.6	$ 205340.5	$ 163371.8
9	$ 37906.5	$ 7659.4	$ 45565.9	$ 205340.5	$ 159774.6
10	$ 41367.8	$ 8119.0	$ 49486.8	$ 205340.5	$ 155853.7
11	$ 45155.6	$ 8606.1	$ 53761.7	$ 205340.5	$ 151578.8
12	$ 49301.2	$ 9122.5	$ 58423.7	$ 205340.5	$ 146916.8
13	$ 53839.2	$ 9669.8	$ 63509.0	$ 205340.5	$ 141831.5
14	$ 58807.4	$ 10250.0	$ 69057.4	$ 205340.5	$ 136283.0
15	$ 64247.6	$ 10865.0	$ 75112.6	$ 205340.5	$ 130227.9
	$ 560054.9	$ 111855.0	$ 1073115.9	$ 3080107.0	$ 2006991.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.007 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.760 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .553 MILLION LBS
TOTAL NITROGEN EXPENDED       =  1.694 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
TWO COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  275821.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                    ----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH =  373.5 GAL/LOADING
                                      DEWAR LOADING  = 2988.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          = 124571.6 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR      =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------- CASH FLOW -------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 31490.8	$ 4805.6	$ 535074.4	$ 218000.3	$ -317074.1
2	$ 34429.3	$ 5093.9	$ 39523.2	$ 218000.3	$ 178477.0
3	$ 37649.0	$ 5399.6	$ 43048.6	$ 218000.3	$ 174951.7
4	$ 41177.4	$ 5723.5	$ 46900.9	$ 218000.3	$ 171099.3
5	$ 45044.4	$ 6067.0	$ 51111.3	$ 218000.3	$ 166888.9
6	$ 49283.0	$ 6431.0	$ 55714.0	$ 218000.3	$ 162286.3
7	$ 53929.5	$ 6816.8	$ 60746.4	$ 218000.3	$ 157253.9
8	$ 59023.8	$ 7225.8	$ 66249.7	$ 218000.3	$ 151750.6
9	$ 64609.6	$ 7659.4	$ 72269.0	$ 218000.3	$ 145731.2
10	$ 70735.0	$ 8119.0	$ 78854.0	$ 218000.3	$ 139146.3
11	$ 77452.8	$ 8606.1	$ 86058.9	$ 218000.3	$ 131941.4
12	$ 84821.0	$ 9122.5	$ 93943.5	$ 218000.3	$ 124056.8
13	$ 92903.5	$ 9669.8	$ 102573.3	$ 218000.3	$ 115427.0
14	$ 101770.2	$ 10250.0	$ 112020.2	$ 218000.3	$ 105980.1
15	$ 111498.1	$ 10865.0	$ 122363.1	$ 218000.3	$ 95637.2
	$ 955817.5	$ 111855.0	$ 1566450.5	$ 3270004.1	$ 1703553.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.704 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.869 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  4.289 MILLION LBS
TOTAL WATER EXPENDED          = 13.580 MILLION GALS
TOTAL POWER EXPENDED          =  9.065 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 547.7 GAL/LOADING
DEWAR LOADING = 4484.8 GAL/LOADING
TOTAL = 144230.6 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 29515.2	$ 4805.6	$ 533098.8	$ 252403.5	$ -280695.3
2	$ 32256.1	$ 5093.9	$ 37350.1	$ 252403.5	$ 215053.4
3	$ 35258.6	$ 5399.6	$ 40658.2	$ 252403.5	$ 211745.3
4	$ 38547.9	$ 5723.5	$ 44271.4	$ 252403.5	$ 208132.1
5	$ 42151.9	$ 6067.0	$ 48218.9	$ 252403.5	$ 204184.6
6	$ 46101.3	$ 6431.0	$ 52532.3	$ 252403.5	$ 199871.2
7	$ 50129.6	$ 6816.8	$ 57246.5	$ 252403.5	$ 195157.0
8	$ 55174.0	$ 7225.8	$ 62399.8	$ 252403.5	$ 190003.7
9	$ 60374.8	$ 7659.4	$ 68034.2	$ 252403.5	$ 184369.3
10	$ 66076.7	$ 8119.0	$ 74195.6	$ 252403.5	$ 178207.9
11	$ 72328.6	$ 8606.1	$ 80934.7	$ 252403.5	$ 171468.8
12	$ 79184.4	$ 9122.5	$ 88306.9	$ 252403.5	$ 164096.6
13	$ 86703.2	$ 9669.8	$ 96373.0	$ 252403.5	$ 156030.5
14	$ 94949.9	$ 10250.0	$ 105199.9	$ 252403.5	$ 147203.6
15	$ 103995.8	$ 10865.0	$ 114860.8	$ 252403.5	$ 137542.7
	$ 893047.9	$ 111855.0	$ 1503680.9	$ 3786052.3	$ 2282371.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.282 MILLION DOLLARS

-------------- IN 15 YEARS --------------------
TOTAL H2 SAVED WITH SYSTEM = 2.163 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .221 MILLION LBS
TOTAL NITROGEN EXPENDED = 3.566 MILLION LBS
TOTAL WATER EXPENDED = 13.580 MILLION GALS
TOTAL POWER EXPENDED = 9.065 MILLION KW-HR

```
   -- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
 TWO COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST          OPERATING COST
  EQUIP AND MATL= $  275821.00     LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00     LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00     POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00     LN2 RATE  =  .041 $/LB
                    -----------    WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA            SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK         HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH =  691.0 GAL/LOADING
                                     DEWAR LOADING  = 5704.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR        TOTAL          =  160260.1 LB/YEAR
  OPERATING LABOR=  6.00           LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00         OPERATIONAL PARAMETERS
  POWER          = 10.00           PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00           NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00           NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  498778.00

YEAR OPERATING   MAINTENANCE  TOTAL COST  GROSS SAVINGS  NET SAVINGS
       COST          COST

  1 $  28185.5  $   4805.6   $ 531769.1  $   280455.2    $ -251314.0
  2 $  30793.6  $   5093.9   $  35887.5  $   280455.2    $  244567.7
  3 $  33649.7  $   5399.6   $  39049.3  $   280455.2    $  241405.9
  4 $  36778.1  $   5723.5   $  42501.7  $   280455.2    $  237953.5
  5 $  40205.2  $   6067.0   $  46272.2  $   280455.2    $  234183.0
  6 $  43959.9  $   6431.0   $  50390.9  $   280455.2    $  230064.3
  7 $  48074.1  $   6816.8   $  54891.0  $   280455.2    $  225564.2
  8 $  52582.9  $   7225.8   $  59808.7  $   280455.2    $  220646.4
  9 $  57524.6  $   7659.4   $  65184.0  $   280455.2    $  215271.2
 10 $  62941.5  $   8119.0   $  71060.5  $   280455.2    $  209394.7
 11 $  68879.9  $   8606.1   $  77486.0  $   280455.2    $  202969.2
 12 $  75390.9  $   9122.5   $  84513.3  $   280455.2    $  195941.8
 13 $  82530.3  $   9669.8   $  92200.1  $   280455.2    $  188255.1
 14 $  90359.7  $  10250.0   $ 100609.7  $   280455.2    $  179845.5
 15 $  98946.5  $  10865.0   $ 109811.5  $   280455.2    $  170643.6
     ---------   ---------    ---------    ---------      ----------
  $  850802.5 $  111855.0 $  1461435.5 $  4206827.8    $  2745392.2

       PAY BACK OCCURS DURING YEAR  3
       NET SAVINGS OVER 15 YEARS = 2.745 MILLION DOLLARS

       -------------- IN 15 YEARS ------------------
       TOTAL H2 SAVED WITH SYSTEM    =  2.404 MILLION LBS
       TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
       TOTAL H2 VENTED BY SYSTEM     =   .443 MILLION LBS
       TOTAL NITROGEN EXPENDED       =  3.080 MILLION LBS
       TOTAL WATER EXPENDED          = 13.580 MILLION GALS
       TOTAL POWER EXPENDED          =  9.065 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING

TWO COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 275821.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 498778.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

ESCALATION RATES, PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 1061.0 GAL/LOADING
  - DEWAR LOADING = 8848.0 GAL/LOADING
  - TOTAL = 201601.6 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 26198.9	$ 4805.6	$ 529782.5	$ 352802.8	$ -176979.7
2	$ 28608.3	$ 5093.9	$ 33702.2	$ 352802.8	$ 319100.6
3	$ 31245.9	$ 5399.6	$ 36645.5	$ 352802.8	$ 316157.3
4	$ 34133.9	$ 5723.5	$ 39857.5	$ 352802.8	$ 312945.3
5	$ 37296.6	$ 6067.0	$ 43363.5	$ 352802.8	$ 309439.3
6	$ 40760.4	$ 6431.0	$ 47191.4	$ 352802.8	$ 305611.4
7	$ 44554.7	$ 6816.8	$ 51371.5	$ 352802.8	$ 301431.3
8	$ 48711.5	$ 7225.8	$ 55937.4	$ 352802.8	$ 296865.5
9	$ 53266.1	$ 7659.4	$ 60925.5	$ 352802.8	$ 291877.4
10	$ 58257.1	$ 8119.0	$ 66376.1	$ 352802.8	$ 286426.8
11	$ 63727.1	$ 8606.1	$ 72333.2	$ 352802.8	$ 280469.6
12	$ 69722.8	$ 9122.5	$ 78845.2	$ 352802.8	$ 273957.6
13	$ 76295.4	$ 9669.8	$ 85965.2	$ 352802.8	$ 266837.6
14	$ 83501.2	$ 10250.0	$ 93751.2	$ 352802.8	$ 259051.6
15	$ 91402.3	$ 10865.0	$ 102267.3	$ 352802.8	$ 250535.5
	$ 787682.1	$ 111855.0	$ 1398315.1	$ 5292042.3	$ 3893727.2

PAY BACK OCCURS DURING YEAR 3

NET SAVINGS OVER 15 YEARS = 3.894 MILLION DOLLARS

-------------- IN 15 YEARS -------------------

- TOTAL H2 SAVED WITH SYSTEM = 3.024 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = 1.107 MILLION LBS
- TOTAL NITROGEN EXPENDED = 2.353 MILLION LBS
- TOTAL WATER EXPENDED = 13.580 MILLION GALS
- TOTAL POWER EXPENDED = 9.065 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 1348.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 227754.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW -------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 48887.2	$ 4805.6	$ 747614.8	$ 398570.8	$ -349043.9
2	$ 53557.2	$ 5093.9	$ 58651.2	$ 398570.8	$ 339919.7
3	$ 58681.2	$ 5399.6	$ 64080.8	$ 398570.8	$ 334490.1
4	$ 64303.6	$ 5723.5	$ 70027.2	$ 398570.8	$ 328543.7
5	$ 70473.6	$ 6067.0	$ 76540.5	$ 398570.8	$ 322030.3
6	$ 77244.9	$ 6431.0	$ 83675.9	$ 398570.8	$ 314895.0
7	$ 84676.8	$ 6816.8	$ 91493.6	$ 398570.8	$ 307077.2
8	$ 92834.3	$ 7225.8	$ 100060.1	$ 398570.8	$ 298510.7
9	$ 101788.9	$ 7659.4	$ 109448.3	$ 398570.8	$ 289122.5
10	$ 111619.3	$ 8119.0	$ 119738.3	$ 398570.8	$ 278832.6
11	$ 122411.8	$ 8606.1	$ 131017.9	$ 398570.8	$ 267552.9
12	$ 134261.5	$ 9122.5	$ 143383.9	$ 398570.8	$ 255186.9
13	$ 147272.5	$ 9669.8	$ 156942.3	$ 398570.8	$ 241628.5
14	$ 161559.6	$ 10250.0	$ 171809.8	$ 398570.8	$ 226761.0
15	$ 177249.4	$ 10865.0	$ 188114.4	$ 398570.8	$ 210456.4
	$ 1506822.1	$ 111855.0	$ 2312599.1	$ 5978562.5	$ 3665963.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.666 MILLION DOLLARS

------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.416 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
TOTAL NITROGEN EXPENDED = 6.618 MILLION LBS
TOTAL WATER EXPENDED = 23.716 MILLION GALS
TOTAL POWER EXPENDED = 15.832 MILLION KW-HR

```
-- LIFE CYCLE COST ------SYSTEM 2  5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  470965.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                    -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH = 1663.0 GAL/LOADING
                                        DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          =  231460.7 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME          =  1.0%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR   =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  693922.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 48433.2	$ 4805.6	$ 747160.8	$ 405056.2	$ -342104.6
2	$ 53057.9	$ 5093.9	$ 58151.8	$ 405056.2	$ 346904.4
3	$ 58131.9	$ 5399.6	$ 63531.5	$ 405056.2	$ 341524.7
4	$ 63699.4	$ 5723.5	$ 69423.0	$ 405056.2	$ 335633.2
5	$ 69808.9	$ 6067.0	$ 75875.9	$ 405056.2	$ 329180.3
6	$ 76513.8	$ 6431.0	$ 82944.8	$ 405056.2	$ 322111.4
7	$ 83872.5	$ 6816.8	$ 90689.4	$ 405056.2	$ 314366.8
8	$ 91949.6	$ 7225.8	$ 99175.5	$ 405056.2	$ 305880.7
9	$ 100815.8	$ 7659.4	$ 108475.2	$ 405056.2	$ 296581.0
10	$ 110548.9	$ 8119.0	$ 118667.9	$ 405056.2	$ 286388.3
11	$ 121234.4	$ 8606.1	$ 129840.5	$ 405056.2	$ 275215.7
12	$ 132966.3	$ 9122.5	$ 142088.7	$ 405056.2	$ 262967.5
13	$ 145847.8	$ 9669.8	$ 155517.6	$ 405056.2	$ 249538.6
14	$ 159992.6	$ 10250.0	$ 170242.6	$ 405056.2	$ 234813.6
15	$ 175525.5	$ 10865.0	$ 186390.5	$ 405056.2	$ 218665.7
	$ 1492398.7	$ 111855.0	$ 2298175.7	$ 6075842.7	$ 3777667.1

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 3.778 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.472 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .052 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.452 MILLION LBS
TOTAL WATER EXPENDED          = 23.716 MILLION GALS
TOTAL POWER EXPENDED          = 15.832 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  470965.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                    ----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH = 1942.0 GAL/LOADING
                                      DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  234743.1 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW -------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 48194.2	$ 4805.6	$ 746921.8	$ 410800.3	$ -336121.5
2	$ 52795.0	$ 5093.9	$ 57888.9	$ 410800.3	$ 352911.4
3	$ 57842.7	$ 5399.6	$ 63242.3	$ 410800.3	$ 347558.1
4	$ 63381.3	$ 5723.5	$ 69104.9	$ 410800.3	$ 341695.5
5	$ 69459.0	$ 6067.0	$ 75526.0	$ 410800.3	$ 335274.4
6	$ 76128.9	$ 6431.0	$ 82559.9	$ 410800.3	$ 328240.5
7	$ 83149.2	$ 6816.8	$ 90266.0	$ 410800.3	$ 320534.4
8	$ 91483.9	$ 7225.8	$ 98709.8	$ 410800.3	$ 312090.6
9	$ 100303.5	$ 7659.4	$ 107962.9	$ 410800.3	$ 302837.4
10	$ 109985.4	$ 8119.0	$ 118104.3	$ 410800.3	$ 292696.0
11	$ 120614.5	$ 8606.1	$ 129220.6	$ 410800.3	$ 281579.7
12	$ 132284.4	$ 9122.5	$ 141406.8	$ 410800.3	$ 269393.5
13	$ 145097.8	$ 9669.8	$ 154767.6	$ 410800.3	$ 256032.8
14	$ 159167.6	$ 10250.0	$ 169417.6	$ 410800.3	$ 241382.8
15	$ 174617.9	$ 10865.0	$ 185482.9	$ 410800.3	$ 225317.4
	$ 1484805.2	$ 111855.0	$ 2290582.2	$ 6162005.2	$ 3871422.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.871 MILLION DOLLARS

```
------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.521 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .104 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.365 MILLION LBS
TOTAL WATER EXPENDED          = 23.716 MILLION GALS
TOTAL POWER EXPENDED          = 15.832 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 24 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2687.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 243507.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 47902.4	$ 4805.6	$ 746630.0	$ 426138.7	$ -320491.3
2	$ 52474.0	$ 5093.9	$ 57567.9	$ 426138.7	$ 368570.8
3	$ 57489.6	$ 5399.6	$ 62889.2	$ 426138.7	$ 363249.5
4	$ 62992.9	$ 5723.5	$ 68716.4	$ 426138.7	$ 357422.3
5	$ 69031.8	$ 6067.0	$ 75098.7	$ 426138.7	$ 351040.0
6	$ 75658.9	$ 6431.0	$ 82089.9	$ 426138.7	$ 344048.8
7	$ 82932.2	$ 6816.8	$ 89749.0	$ 426138.7	$ 336389.7
8	$ 90915.2	$ 7225.8	$ 98141.1	$ 426138.7	$ 327997.6
9	$ 99678.0	$ 7659.4	$ 107337.4	$ 426138.7	$ 318801.3
10	$ 109297.3	$ 8119.0	$ 117416.3	$ 426138.7	$ 308722.4
11	$ 119857.6	$ 8606.1	$ 128463.7	$ 426138.7	$ 297675.0
12	$ 131451.8	$ 9122.5	$ 140574.3	$ 426138.7	$ 285564.4
13	$ 144181.9	$ 9669.8	$ 153851.7	$ 426138.7	$ 272287.0
14	$ 158160.1	$ 10250.0	$ 168410.1	$ 426138.7	$ 257728.6
15	$ 173509.8	$ 10865.0	$ 184374.8	$ 426138.7	$ 241763.9
	$ 1475533.5	$ 111855.0	$ 2281310.5	$ 6392080.5	$ 4110770.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.111 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.653 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .261 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.258 MILLION LBS
TOTAL WATER EXPENDED = 23.716 MILLION GALS
TOTAL POWER EXPENDED = 15.832 MILLION KW-HR

```
-- LIFE CYCLE COST -------SYSTEM 1  NO VENTING
ONE COMPRESSOR, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST               OPERATING COST
  EQUIP AND MATL= $  178249.00          LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00          LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00          POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00          LN2 RATE  =  .041 $/LB
                    ----------          WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                 SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK              HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                  NORMAL BOILOFF =   400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR              SHUTTLE LAUNCH =      0.  GAL/LOADING
                                          DEWAR LOADING  =      0.  GAL/LOADING
ESCALATION RATES,PERCENT/YEAR             TOTAL          =  80901.8 LB/YEAR
  OPERATING LABOR=  6.00                LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00              OPERATIONAL PARAMETERS
  POWER          = 10.00                PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00                NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW ------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  401206.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23193.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
	$ 632151.2	$ 111855.0	$ 1145212.2	$ 2123672.9	$ 978460.7

```
PAY BACK OCCURS DURING YEAR  4
NET SAVINGS OVER 15 YEARS =  .978 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM     =  1.214 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED        =  2.524 MILLION LBS
TOTAL WATER EXPENDED           =  8.624 MILLION GALS
TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 178249.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 401206.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 40.4 GAL/LOADING
DEWAR LOADING = 692.8 GAL/LOADING
TOTAL = 89528.4 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------- CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20364.5	$ 4805.6	$ 426376.1	$ 156674.6	$ -269701.4
2	$ 22194.3	$ 5093.9	$ 27288.3	$ 156674.6	$ 129386.4
3	$ 24194.8	$ 5399.6	$ 29594.4	$ 156674.6	$ 127080.3
4	$ 26382.2	$ 5723.5	$ 32105.7	$ 156674.6	$ 124568.9
5	$ 28774.3	$ 6067.0	$ 34841.3	$ 156674.6	$ 121833.3
6	$ 31391.0	$ 6431.0	$ 37821.9	$ 156674.6	$ 118852.7
7	$ 34253.6	$ 6816.8	$ 41070.5	$ 156674.6	$ 115604.2
8	$ 37385.9	$ 7225.8	$ 44611.8	$ 156674.6	$ 112062.8
9	$ 40813.9	$ 7659.4	$ 48473.3	$ 156674.6	$ 108201.3
10	$ 44566.1	$ 8119.0	$ 52685.0	$ 156674.6	$ 103989.6
11	$ 48673.7	$ 8606.1	$ 57279.8	$ 156674.6	$ 99394.9
12	$ 53171.1	$ 9122.5	$ 62293.5	$ 156674.6	$ 94381.1
13	$ 58096.0	$ 9669.8	$ 67765.8	$ 156674.6	$ 88908.8
14	$ 63490.0	$ 10250.0	$ 73740.0	$ 156674.6	$ 82934.7
15	$ 69398.3	$ 10865.0	$ 80263.3	$ 156674.6	$ 76411.3
	$ 603149.6	$ 111855.0	$ 1116210.6	$ 2350119.5	$ 1233908.9

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = 1.234 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 1.343 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .105 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.190 MILLION LBS
TOTAL WATER EXPENDED = 8.624 MILLION GALS
TOTAL POWER EXPENDED = 5.758 MILLION KW-HR

```
-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =   74.4 GAL/LOADING
                                         DEWAR LOADING  = 1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  96798.4 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME             =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  401206.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19831.1	$ 4805.6	$ 425842.7	$ 169397.2	$ -256445.4
2	$ 21607.6	$ 5093.9	$ 26701.5	$ 169397.2	$ 142695.7
3	$ 23549.4	$ 5399.6	$ 28948.9	$ 169397.2	$ 140448.3
4	$ 25672.2	$ 5723.5	$ 31395.7	$ 169397.2	$ 138001.5
5	$ 27993.4	$ 6067.0	$ 34060.3	$ 169397.2	$ 135336.9
6	$ 30531.9	$ 6431.0	$ 36962.9	$ 169397.2	$ 132434.3
7	$ 33308.7	$ 6816.8	$ 40125.5	$ 169397.2	$ 129271.7
8	$ 36346.5	$ 7225.8	$ 43572.3	$ 169397.2	$ 125824.9
9	$ 39670.5	$ 7659.4	$ 47329.9	$ 169397.2	$ 122067.3
10	$ 43308.3	$ 8119.0	$ 51427.3	$ 169397.2	$ 117970.0
11	$ 47290.1	$ 8606.1	$ 55896.2	$ 169397.2	$ 113501.0
12	$ 51649.2	$ 9122.5	$ 60771.7	$ 169397.2	$ 108625.6
13	$ 56422.0	$ 9669.8	$ 66091.8	$ 169397.2	$ 103305.5
14	$ 61648.5	$ 10250.0	$ 71898.5	$ 169397.2	$ 97498.8
15	$ 67372.7	$ 10865.0	$ 78237.7	$ 169397.2	$ 91159.5
	$ 586202.0	$ 111855.0	$ 1099263.0	$ 2540958.6	$ 1441695.6

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 1.442 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.452 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .209 MILLION LBS
TOTAL NITROGEN EXPENDED       =  1.995 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  178249.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                   -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =   400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH =   163.7 GAL/LOAD
                                      DEWAR LOADING  = 2769.6 GAL/LOAD
ESCALATION RATES,PERCENT/YEAR         TOTAL          = 115411.5 LB/YEA
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME             =  5.
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19133.0	$ 4805.6	$ 425144.6	$ 201970.1	$ -223174.5
2	$ 20839.7	$ 5093.9	$ 25933.7	$ 201970.1	$ 176036.5
3	$ 22704.7	$ 5399.6	$ 28104.3	$ 201970.1	$ 173865.8
4	$ 24743.1	$ 5723.5	$ 30466.7	$ 201970.1	$ 171503.5
5	$ 26971.4	$ 6067.0	$ 33038.3	$ 201970.1	$ 168931.8
6	$ 29407.7	$ 6431.0	$ 35838.7	$ 201970.1	$ 166131.5
7	$ 32072.0	$ 6816.8	$ 38888.9	$ 201970.1	$ 163081.3
8	$ 34986.2	$ 7225.8	$ 42212.1	$ 201970.1	$ 159758.1
9	$ 38174.2	$ 7659.4	$ 45833.6	$ 201970.1	$ 156136.5
10	$ 41662.4	$ 8119.0	$ 49781.3	$ 201970.1	$ 152188.8
11	$ 45479.6	$ 8606.1	$ 54085.7	$ 201970.1	$ 147884.4
12	$ 49657.6	$ 9122.5	$ 58780.1	$ 201970.1	$ 143190.1
13	$ 54231.2	$ 9669.8	$ 63901.0	$ 201970.1	$ 138069.1
14	$ 59238.7	$ 10250.0	$ 69488.7	$ 201970.1	$ 132481.5
15	$ 64721.9	$ 10865.0	$ 75586.9	$ 201970.1	$ 126383.2
	$ 564023.5	$ 111855.0	$ 1077084.5	$ 3029552.2	$ 1952467.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.952 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM     =  1.731 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =   .523 MILLION LBS
TOTAL NITROGEN EXPENDED        =  1.740 MILLION LBS
TOTAL WATER EXPENDED           =  8.624 MILLION GALS
TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
TWO COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 186.7 GAL/LOADING
DEWAR LOADING = 2988.0 GAL/LOADING
TOTAL = 122374.5 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30969.4	$ 4805.6	$ 534553.0	$ 214155.4	$ -320397.7
2	$ 33856.1	$ 5093.9	$ 38950.0	$ 214155.4	$ 175205.4
3	$ 37018.7	$ 5399.6	$ 42418.3	$ 214155.4	$ 171737.1
4	$ 40434.2	$ 5723.5	$ 46207.8	$ 214155.4	$ 167947.6
5	$ 44282.1	$ 6067.0	$ 50349.1	$ 214155.4	$ 163806.3
6	$ 48444.8	$ 6431.0	$ 54875.8	$ 214155.4	$ 159279.6
7	$ 53007.8	$ 6816.8	$ 59824.6	$ 214155.4	$ 154330.8
8	$ 58010.2	$ 7225.8	$ 65236.0	$ 214155.4	$ 148919.4
9	$ 63494.9	$ 7659.4	$ 71154.3	$ 214155.4	$ 143001.1
10	$ 69509.1	$ 8119.0	$ 77628.1	$ 214155.4	$ 136527.3
11	$ 76104.7	$ 8606.1	$ 84710.8	$ 214155.4	$ 129444.6
12	$ 83338.5	$ 9122.5	$ 92460.9	$ 214155.4	$ 121694.5
13	$ 91273.0	$ 9669.8	$ 100942.8	$ 214155.4	$ 113212.6
14	$ 99977.1	$ 10250.0	$ 110227.1	$ 214155.4	$ 103928.3
15	$ 109526.1	$ 10865.0	$ 120391.1	$ 214155.4	$ 93764.3
	$ 939296.6	$ 111855.0	$ 1549929.6	$ 3212330.8	$ 1662401.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.662 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 1.836 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
TOTAL NITROGEN EXPENDED = 4.198 MILLION LBS
TOTAL WATER EXPENDED = 13.329 MILLION GALS
TOTAL POWER EXPENDED = 8.898 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 275821.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 498778.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 273.9 GAL/LOADING
  - DEWAR LOADING = 4484.8 GAL/LOADING
  - TOTAL = 141008.6 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 29103.6	$ 4805.6	$ 532687.2	$ 246765.4	$ -285921.9
2	$ 31803.6	$ 5093.9	$ 36897.6	$ 246765.4	$ 209867.8
3	$ 34761.0	$ 5399.6	$ 40160.6	$ 246765.4	$ 206604.8
4	$ 38000.8	$ 5723.5	$ 43724.3	$ 246765.4	$ 203041.0
5	$ 41550.3	$ 6067.0	$ 47617.3	$ 246765.4	$ 199148.1
6	$ 45439.8	$ 6431.0	$ 51870.8	$ 246765.4	$ 194894.6
7	$ 49702.3	$ 6816.8	$ 56519.2	$ 246765.4	$ 190246.2
8	$ 54374.2	$ 7225.8	$ 61600.0	$ 246765.4	$ 185165.3
9	$ 59495.3	$ 7659.4	$ 67154.7	$ 246765.4	$ 179610.7
10	$ 65109.6	$ 8119.0	$ 73228.5	$ 246765.4	$ 173536.8
11	$ 71265.2	$ 8606.1	$ 79871.3	$ 246765.4	$ 166894.1
12	$ 78015.0	$ 9122.5	$ 87137.5	$ 246765.4	$ 159627.9
13	$ 85417.2	$ 9669.8	$ 95087.0	$ 246765.4	$ 151678.3
14	$ 93535.7	$ 10250.0	$ 103785.7	$ 246765.4	$ 142979.7
15	$ 102440.6	$ 10865.0	$ 113305.6	$ 246765.4	$ 133459.8
	$ 880014.2	$ 111855.0	$ 1490647.2	$ 3701480.3	$ 2210833.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.211 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
- TOTAL H2 SAVED WITH SYSTEM = 2.115 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = .209 MILLION LBS
- TOTAL NITROGEN EXPENDED = 3.515 MILLION LBS
- TOTAL WATER EXPENDED = 13.329 MILLION GALS
- TOTAL POWER EXPENDED = 8.898 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 345.5 GAL/LOADING
DEWAR LOADING = 5704.0 GAL/LOADING
TOTAL = 156195.4 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 27847.4	$ 4805.6	$ 531431.0	$ 273341.9	$ -258089.1
2	$ 30421.8	$ 5093.9	$ 35515.7	$ 273341.9	$ 237826.2
3	$ 33241.0	$ 5399.6	$ 38640.6	$ 273341.9	$ 234701.3
4	$ 36328.7	$ 5723.5	$ 42052.3	$ 273341.9	$ 231289.6
5	$ 39711.1	$ 6067.0	$ 45778.0	$ 273341.9	$ 227563.8
6	$ 43416.6	$ 6431.0	$ 49847.6	$ 273341.9	$ 223494.3
7	$ 47476.8	$ 6816.8	$ 54293.7	$ 273341.9	$ 219048.2
8	$ 51926.1	$ 7225.8	$ 59152.0	$ 273341.9	$ 214189.9
9	$ 56802.5	$ 7659.4	$ 64461.9	$ 273341.9	$ 208880.0
10	$ 62147.5	$ 8119.0	$ 70266.4	$ 273341.9	$ 203075.5
11	$ 68006.8	$ 8606.1	$ 76612.9	$ 273341.9	$ 196729.0
12	$ 74430.8	$ 9122.5	$ 83553.3	$ 273341.9	$ 189788.6
13	$ 81474.6	$ 9669.8	$ 91144.4	$ 273341.9	$ 182197.5
14	$ 89198.8	$ 10250.0	$ 99448.8	$ 273341.9	$ 173893.1
15	$ 97670.0	$ 10865.0	$ 108535.0	$ 273341.9	$ 164806.9
	$ 840100.5	$ 111855.0	$ 1450733.5	$ 4100128.4	$ 2649394.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.649 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 2.343 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .418 MILLION LBS
TOTAL NITROGEN EXPENDED = 3.056 MILLION LBS
TOTAL WATER EXPENDED = 13.329 MILLION GALS
TOTAL POWER EXPENDED = 8.898 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 530.5 GAL/LOADING
DEWAR LOADING = 8848.0 GAL/LOADING
TOTAL = 195360.4 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 25970.0	$ 4805.6	$ 529553.6	$ 341880.7	$ -187672.9
2	$ 28356.6	$ 5093.9	$ 33450.5	$ 341880.7	$ 308430.1
3	$ 30969.3	$ 5399.6	$ 36363.9	$ 341880.7	$ 305511.8
4	$ 33829.9	$ 5723.5	$ 39553.4	$ 341880.7	$ 302327.2
5	$ 36962.4	$ 6067.0	$ 43029.3	$ 341880.7	$ 298851.4
6	$ 40393.0	$ 6431.0	$ 46824.0	$ 341880.7	$ 295056.7
7	$ 44150.9	$ 6816.8	$ 50967.7	$ 341880.7	$ 290913.0
8	$ 48267.6	$ 7225.8	$ 55493.4	$ 341880.7	$ 286387.3
9	$ 52778.0	$ 7659.4	$ 60437.4	$ 341880.7	$ 281443.2
10	$ 57720.6	$ 8119.0	$ 65839.5	$ 341880.7	$ 276041.1
11	$ 63137.3	$ 8606.1	$ 71743.4	$ 341880.7	$ 270137.3
12	$ 69074.3	$ 9122.5	$ 78196.8	$ 341880.7	$ 263683.9
13	$ 75582.4	$ 9669.8	$ 85252.3	$ 341880.7	$ 256628.4
14	$ 82717.4	$ 10250.0	$ 92967.4	$ 341880.7	$ 248913.2
15	$ 90540.5	$ 10865.0	$ 101405.5	$ 341880.7	$ 240475.1
	$ 780450.2	$ 111855.0	$ 1391083.2	$ 5128210.1	$ 3737127.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.737 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 2.930 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 1.045 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.369 MILLION LBS
TOTAL WATER EXPENDED = 13.329 MILLION GALS
TOTAL POWER EXPENDED = 8.898 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 470965.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 674.0 GAL/LOADING
  - DEWAR LOADING =10784.0 GAL/LOADING
  - TOTAL = 219825.3 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

CASH FLOW

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 47399.4	$ 4805.6	$ 746127.0	$ 384694.3	$ -361432.7
2	$ 51921.3	$ 5093.9	$ 57015.3	$ 384694.3	$ 327679.0
3	$ 56882.4	$ 5399.6	$ 62281.9	$ 384694.3	$ 322412.3
4	$ 62325.7	$ 5723.5	$ 68049.2	$ 384694.3	$ 316645.0
5	$ 68298.6	$ 6067.0	$ 74365.5	$ 384694.3	$ 310328.7
6	$ 74853.2	$ 6431.0	$ 81284.2	$ 384694.3	$ 303410.1
7	$ 82046.8	$ 6816.8	$ 88863.6	$ 384694.3	$ 295830.6
8	$ 89942.3	$ 7225.8	$ 97168.1	$ 384694.3	$ 287526.2
9	$ 98608.7	$ 7659.4	$ 106268.1	$ 384694.3	$ 278426.2
10	$ 108122.1	$ 8119.0	$ 116241.1	$ 384694.3	$ 268453.2
11	$ 118566.0	$ 8606.1	$ 127172.1	$ 384694.3	$ 257522.2
12	$ 130032.2	$ 9122.5	$ 139154.6	$ 384694.3	$ 245539.6
13	$ 142621.6	$ 9669.8	$ 152291.4	$ 384694.3	$ 232402.9
14	$ 156445.1	$ 10250.0	$ 166695.1	$ 384694.3	$ 217999.2
15	$ 171624.6	$ 10865.0	$ 182489.6	$ 384694.3	$ 202204.7
	$ 1459689.8	$ 111855.0	$ 2265466.8	$ 5770413.8	$ 3504947.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.505 MILLION DOLLARS

IN 15 YEARS

- TOTAL H2 SAVED WITH SYSTEM = 3.297 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
- TOTAL NITROGEN EXPENDED = 6.398 MILLION LBS
- TOTAL WATER EXPENDED = 22.902 MILLION GALS
- TOTAL POWER EXPENDED = 15.288 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 831.5 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 221678.2 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 47172.4	$ 4805.6	$ 745900.0	$ 387936.9	$ -357963.1
2	$ 51671.6	$ 5093.9	$ 56765.6	$ 387936.9	$ 331171.3
3	$ 56607.7	$ 5399.6	$ 62007.3	$ 387936.9	$ 325929.6
4	$ 62[illegible].6	$ 5723.5	$ 67747.1	$ 387936.9	$ 320189.8
5	$ 679[illegible].3	$ 6067.0	$ 74033.2	$ 387936.9	$ 313903.7
6	$ 74487.7	$ 6431.0	$ 80918.7	$ 387936.9	$ 307018.3
7	$ 81644.7	$ 6816.8	$ 88461.5	$ 387936.9	$ 299475.4
8	$ 89499.9	$ 7225.8	$ 96725.8	$ 387936.9	$ 291211.1
9	$ 98122.1	$ 7659.4	$ 105781.5	$ 387936.9	$ 282155.4
10	$ 107586.9	$ 8119.0	$ 115705.8	$ 387936.9	$ 272231.1
11	$ 117977.3	$ 8606.1	$ 126583.4	$ 387936.9	$ 261353.6
12	$ 129384.6	$ 9122.5	$ 138507.1	$ 387936.9	$ 249429.9
13	$ 141909.2	$ 9669.8	$ 151579.0	$ 387936.9	$ 236357.9
14	$ 155661.5	$ 10250.0	$ 165911.5	$ 387936.9	$ 222025.5
15	$ 170762.6	$ 10865.0	$ 181627.6	$ 387936.9	$ 206309.3
	$ 1452478.1	$ 111855.0	$ 2258255.1	$ 5819053.9	$ 3560798.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.561 MILLION DOLLARS

------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.325 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .026 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.315 MILLION LBS
TOTAL WATER EXPENDED = 22.902 MILLION GALS
TOTAL POWER EXPENDED = 15.288 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 971.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 223319.4 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 47052.9	$ 4805.6	$ 745780.5	$ 390809.0	$ -354971.5
2	$ 51540.2	$ 5093.9	$ 56634.1	$ 390809.0	$ 334174.9
3	$ 56463.1	$ 5399.6	$ 61862.7	$ 390809.0	$ 328946.3
4	$ 61864.5	$ 5723.5	$ 67588.1	$ 390809.0	$ 323221.0
5	$ 67791.3	$ 6067.0	$ 73858.3	$ 390809.0	$ 316950.7
6	$ 74295.2	$ 6431.0	$ 80726.2	$ 390809.0	$ 310082.8
7	$ 81433.0	$ 6816.8	$ 88249.8	$ 390809.0	$ 302559.2
8	$ 89267.1	$ 7225.8	$ 96492.9	$ 390809.0	$ 294316.1
9	$ 97866.0	$ 7659.4	$ 105525.4	$ 390809.0	$ 285283.6
10	$ 107305.1	$ 8119.0	$ 115424.1	$ 390809.0	$ 275384.9
11	$ 117667.3	$ 8606.1	$ 126273.4	$ 390809.0	$ 264535.6
12	$ 129043.6	$ 9122.5	$ 138166.1	$ 390809.0	$ 252642.9
13	$ 141534.2	$ 9669.8	$ 151204.0	$ 390809.0	$ 239605.0
14	$ 155248.9	$ 10250.0	$ 165498.9	$ 390809.0	$ 225310.1
15	$ 170308.8	$ 10865.0	$ 181173.8	$ 390809.0	$ 209635.2
	$ 1448681.4	$ 111855.0	$ 2254458.4	$ 5862135.1	$ 3607676.7

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.608 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.350 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .052 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.271 MILLION LBS
TOTAL WATER EXPENDED = 22.902 MILLION GALS
TOTAL POWER EXPENDED = 15.288 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST                  OPERATING COST
  EQUIP AND MATL= $  470965.00             LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00             LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00             POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00             LN2 RATE  =  .041 $/LB
                    -----------            WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                    SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK                 HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                     NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR                 SHUTTLE LAUNCH = 1343.5 GAL/LOADING
                                             DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR                TOTAL          =  227701.8 LB/YEAR
  OPERATING LABOR=  6.00                   LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00                 OPERATIONAL PARAMETERS
  POWER          = 10.00                   PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00                   NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                   NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 46907.0	$ 4805.6	$ 745634.6	$ 398478.2	$ -347156.4
2	$ 51379.7	$ 5093.9	$ 56473.6	$ 398478.2	$ 342004.5
3	$ 56286.6	$ 5399.6	$ 61686.2	$ 398478.2	$ 336792.0
4	$ 61670.3	$ 5723.5	$ 67393.9	$ 398478.2	$ 331084.3
5	$ 67577.7	$ 6067.0	$ 73644.7	$ 398478.2	$ 324833.5
6	$ 74060.2	$ 6431.0	$ 80491.2	$ 398478.2	$ 317987.0
7	$ 81174.5	$ 6816.8	$ 87991.4	$ 398478.2	$ 310486.8
8	$ 88982.7	$ 7225.8	$ 96208.6	$ 398478.2	$ 302269.6
9	$ 97553.2	$ 7659.4	$ 105212.6	$ 398478.2	$ 293265.6
10	$ 106961.1	$ 8119.0	$ 115080.0	$ 398478.2	$ 283398.1
11	$ 117288.9	$ 8606.1	$ 125895.0	$ 398478.2	$ 272583.2
12	$ 128627.4	$ 9122.5	$ 137749.8	$ 398478.2	$ 260728.4
13	$ 141076.3	$ 9669.8	$ 150746.1	$ 398478.2	$ 247732.1
14	$ 154745.2	$ 10250.0	$ 164995.2	$ 398478.2	$ 233483.0
15	$ 169754.8	$ 10865.0	$ 180619.8	$ 398478.2	$ 217858.4
	$ 1444045.6	$ 111855.0	$ 2249822.6	$ 5977172.8	$ 3727350.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.727 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

```
TOTAL H2 SAVED WITH SYSTEM    =  3.416 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .130 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.218 MILLION LBS
TOTAL WATER EXPENDED          = 22.902 MILLION GALS
TOTAL POWER EXPENDED          = 15.288 MILLION KW-HR
```

6% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST               OPERATING COST
  EQUIP AND MATL= $  178249.00          LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00          LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00          POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00          LN2 RATE  =  .041 $/LB
                    -----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                 SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK              HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =     0.  GAL/LOADING
                                         DEWAR LOADING  =     0.  GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =   80901.8 LB/YEAR
  OPERATING LABOR=  6.00                LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00              OPERATIONAL PARAMETERS
  POWER          = 10.00                PERCENT DOWN TIME                =  5.8%
  LIQ NITROGEN   = 10.00                NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  6.00
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 150072.9	$ 121780.5
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 159077.3	$ 128378.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 168621.9	$ 135301.3
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 178739.2	$ 142561.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 189463.6	$ 150171.6
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 200831.4	$ 158143.9
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 212881.3	$ 166490.7
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 225654.1	$ 175224.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 239193.4	$ 184356.1
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 253545.0	$ 193897.7
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 268757.7	$ 203859.9
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 284883.1	$ 214252.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 301976.1	$ 225085.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 320094.7	$ 236365.1
	$ 632151.2	$ 111855.0	$ 1145212.2	$ 3295369.7	$ 2150157.5

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = 2.150 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.214 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.524 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

6% H_2 ESCALATION RATE

```
    -- LIFE CYCLE COST ------SYSTEM 1  5% VENTING
  ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  178249.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                    -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  161.8 GAL/LOADING
                                       DEWAR LOADING  =  692.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  90956.0 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  =  6.00
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20203.1	$ 4805.6	$ 426214.7	$ 159173.0	$ -267041.6
2	$ 22016.8	$ 5093.9	$ 27110.7	$ 168723.4	$ 141612.7
3	$ 23999.5	$ 5399.6	$ 29399.1	$ 178846.8	$ 149447.7
4	$ 26167.4	$ 5723.5	$ 31890.9	$ 189577.6	$ 157686.7
5	$ 28538.1	$ 6067.0	$ 34605.0	$ 200952.3	$ 166347.3
6	$ 31131.1	$ 6431.0	$ 37562.0	$ 213009.4	$ 175447.4
7	$ 33967.7	$ 6816.8	$ 40784.6	$ 225790.0	$ 185005.4
8	$ 37071.5	$ 7225.8	$ 44297.3	$ 239337.4	$ 195040.1
9	$ 40468.0	$ 7659.4	$ 48127.4	$ 253697.6	$ 205570.3
10	$ 44185.5	$ 8119.0	$ 52304.5	$ 268919.5	$ 216615.0
11	$ 48255.1	$ 8606.1	$ 56861.2	$ 285054.7	$ 228193.5
12	$ 52710.6	$ 9122.5	$ 61833.1	$ 302157.9	$ 240324.9
13	$ 57589.5	$ 9669.8	$ 67259.3	$ 320287.4	$ 253028.1
14	$ 62932.8	$ 10250.0	$ 73182.8	$ 339504.7	$ 266321.9
15	$ 68785.5	$ 10865.0	$ 79650.5	$ 359875.0	$ 280224.5
	$ 598022.0	$ 111855.0	$ 1111083.0	$ 3704906.8	$ 2593823.8

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 2.594 MILLION DOLLARS

------------- IN 15 YEARS -----------------
TOTAL H2 SAVED WITH SYSTEM    =  1.364 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .123 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.131 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

6% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  178249.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                   -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH =  297.6 GAL/LOADING
                                      DEWAR LOADING  = 1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  99424.3 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  =  6.00
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19576.2	$ 4805.6	$ 425587.8	$ 173992.6	$ -251595.2
2	$ 21327.2	$ 5093.9	$ 26421.1	$ 184432.1	$ 158011.0
3	$ 23240.9	$ 5399.6	$ 28640.5	$ 195498.0	$ 166857.5
4	$ 25332.9	$ 5723.5	$ 31056.5	$ 207227.9	$ 176171.5
5	$ 27620.2	$ 6067.0	$ 33687.1	$ 219661.6	$ 185974.5
6	$ 30121.4	$ 6431.0	$ 36552.4	$ 232841.3	$ 196288.9
7	$ 32857.1	$ 6816.8	$ 39673.9	$ 246811.8	$ 207137.9
8	$ 35849.7	$ 7225.8	$ 43075.6	$ 261620.5	$ 218544.9
9	$ 39124.1	$ 7659.4	$ 46783.5	$ 277317.7	$ 230534.2
10	$ 42707.3	$ 8119.0	$ 50826.2	$ 293956.8	$ 243130.6
11	$ 46629.0	$ 8606.1	$ 55235.1	$ 311594.2	$ 256359.1
12	$ 50921.9	$ 9122.5	$ 60044.4	$ 330289.8	$ 270245.5
13	$ 55622.0	$ 9669.8	$ 65291.8	$ 350107.2	$ 284815.5
14	$ 60768.5	$ 10250.0	$ 71018.5	$ 371113.7	$ 300095.2
15	$ 66404.7	$ 10865.0	$ 77269.7	$ 393380.5	$ 316110.8
	$ 578103.0	$ 111855.0	$ 1091164.0	$ 4049845.8	$ 2958681.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.959 MILLION DOLLARS

------------- IN 15 YEARS ------------------

```
TOTAL H2 SAVED WITH SYSTEM    =  1.491 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
TOTAL NITROGEN EXPENDED       =  1.902 MILLION LBS
TCTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

6% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST		OPERATING COST	
EQUIP AND MATL=	$ 178249.00	LABOR TIME=	8.0 HR/WEEK
DETAILED DESIGN=	$ 47134.00	LABOR RATE=	12.00 $/HR
FABRICATION =	$ 123940.00	POWER RATE=	.024 $/KW-HR
INSTALLATION =	$ 51883.00	LN2 RATE =	.041 $/LB
	-----------	WATER RATE=	.0003 $/GAL
TOTAL * (1.00)	$ 401206.00		

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 654.8 GAL/LOADING
DEWAR LOADING = 2769.6 GAL/LOADING
TOTAL = 121189.2 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 6.00

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 18759.3	$ 4805.6	$ 424769.9	$ 212081.1	$ -212688.8
2	$ 20427.5	$ 5093.9	$ 25521.5	$ 224806.0	$ 199284.5
3	$ 22251.3	$ 5399.6	$ 27650.9	$ 238294.3	$ 210643.4
4	$ 24244.3	$ 5723.5	$ 29967.9	$ 252592.0	$ 222624.1
5	$ 26422.7	$ 6067.0	$ 32489.7	$ 267747.5	$ 235257.8
6	$ 28804.2	$ 6431.0	$ 35235.2	$ 283812.4	$ 248577.2
7	$ 31408.2	$ 6816.8	$ 38225.0	$ 300841.1	$ 262616.1
8	$ 34256.0	$ 7225.8	$ 41481.8	$ 318891.6	$ 277409.8
9	$ 37370.9	$ 7659.4	$ 45030.3	$ 338025.1	$ 292994.7
10	$ 40778.8	$ 8119.0	$ 48897.7	$ 358306.6	$ 309408.8
11	$ 44507.7	$ 8606.1	$ 53113.8	$ 379805.0	$ 326691.2
12	$ 48588.5	$ 9122.5	$ 57710.9	$ 402593.3	$ 344882.3
13	$ 53055.2	$ 9669.8	$ 62725.0	$ 426748.9	$ 364023.9
14	$ 57945.0	$ 10250.0	$ 68195.0	$ 452353.8	$ 384158.8
15	$ 63298.9	$ 10865.0	$ 74163.9	$ 479495.0	$ 405331.1
	---------	---------	---------	---------	---------
	$ 552117.5	$ 111855.0	$ 1065178.5	$ 4936393.5	$ 3871215.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.871 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 1.818 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .615 MILLION LBS
TOTAL NITROGEN EXPENDED = 1.603 MILLION LBS
TOTAL WATER EXPENDED = 8.624 MILLION GALS
TOTAL POWER EXPENDED = 5.758 MILLION KW-HR

6% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  275821.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                    -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH =  747.0 GAL/LOADING
                                        DEWAR LOADING  = 2988.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          = 128965.7 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  6.00
```

------------------------- CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32533.4	$ 4805.6	$ 536117.0	$ 225690.0	$ -310427.0
2	$ 35575.8	$ 5093.9	$ 40669.7	$ 239231.4	$ 198561.7
3	$ 38909.8	$ 5399.6	$ 44309.3	$ 253585.3	$ 209276.0
4	$ 42563.7	$ 5723.5	$ 48287.3	$ 268800.4	$ 220513.2
5	$ 46568.9	$ 6067.0	$ 52635.8	$ 284928.5	$ 232292.7
6	$ 50959.4	$ 6431.0	$ 57390.4	$ 302024.2	$ 244633.8
7	$ 55773.1	$ 6816.8	$ 62589.9	$ 320145.6	$ 257555.7
8	$ 61051.2	$ 7225.8	$ 68277.0	$ 339354.4	$ 271077.4
9	$ 66839.1	$ 7659.4	$ 74498.5	$ 359715.6	$ 285217.2
10	$ 73186.8	$ 8119.0	$ 81305.7	$ 381298.6	$ 299992.8
11	$ 80149.1	$ 8606.1	$ 88755.2	$ 404176.5	$ 315421.3
12	$ 87786.2	$ 9122.5	$ 96908.7	$ 428427.1	$ 331518.4
13	$ 96164.4	$ 9669.8	$ 105834.2	$ 454132.7	$ 348298.5
14	$ 105356.4	$ 10250.0	$ 115606.4	$ 481380.7	$ 365774.3
15	$ 115442.1	$ 10865.0	$ 126307.1	$ 510263.5	$ 383956.4
	$ 988859.2	$ 111855.0	$ 1599492.2	$ 5253154.6	$ 3653662.4

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.654 MILLION DOLLARS

```
--------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.934 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  4.471 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

6% H_2 ESCALATION RATE

```
-- LIFE CYCLE COST ------SYSTEM 1  5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  275821.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE   =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 1095.4 GAL/LOADING
                                         DEWAR LOADING  = 4484.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  150674.1 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  6.00

----------------------- CASH FLOW -------------------------------
         TOTAL CAPITAL INVESTMENT COST = $  498778.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30338.3	$ 4805.6	$ 533921.9	$ 263679.8	$ -270242.1
2	$ 33161.2	$ 5093.9	$ 38255.1	$ 279500.5	$ 241245.4
3	$ 36253.7	$ 5399.6	$ 41653.3	$ 296270.6	$ 254617.3
4	$ 39642.0	$ 5723.5	$ 45365.6	$ 314046.8	$ 268681.2
5	$ 43355.0	$ 6067.0	$ 49422.0	$ 332889.6	$ 283467.7
6	$ 4742?.2	$ 6431.0	$ 53855.2	$ 352863.0	$ 299007.8
7	$ 51884.3	$ 6816.8	$ 58701.1	$ 374034.8	$ 315333.6
8	$ 56773.5	$ 7225.8	$ 63999.4	$ 396476.9	$ 332477.5
9	$ 62133.7	$ 7659.4	$ 69793.1	$ 420265.5	$ 350472.4
10	$ 68010.8	$ 8119.0	$ 76129.8	$ 445481.4	$ 369351.6
11	$ 74455.5	$ 8606.1	$ 83061.6	$ 472210.3	$ 389148.7
12	$ 81523.3	$ 9122.5	$ 90645.8	$ 500542.9	$ 409897.1
13	$ 89275.2	$ 9669.8	$ 98945.0	$ 530575.5	$ 431630.5
14	$ 97778.3	$ 10250.0	$ 108028.3	$ 562410.0	$ 454381.7
15	$ 107106.2	$ 10865.0	$ 117971.2	$ 596154.6	$ 478183.5
	$ 919115.2	$ 111855.0	$ 1529748.2	$ 6137402.1	$ 4607653.9

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 4.608 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  2.260 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
TOTAL NITROGEN EXPENDED       =  3.668 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

6% H_2 ESCALATION RATE

-- *LIFE CYCLE COST ------SYSTEM 1 10% VENTING*
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  275821.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                   -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH = 1362.0 GAL/LOADING
                                      DEWAR LOADING  = 5704.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  168389.6 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  =  6.00
```

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 28861.9	$ 4805.6	$ 532445.5	$ 294681.8	$ -237763.7
2	$ 31537.1	$ 5093.9	$ 36631.1	$ 312362.7	$ 275731.6
3	$ 34467.3	$ 5399.6	$ 39866.8	$ 331104.4	$ 291237.6
4	$ 37677.0	$ 5723.5	$ 43400.5	$ 350970.7	$ 307570.2
5	$ 41193.4	$ 6067.0	$ 47260.4	$ 372028.9	$ 324768.6
6	$ 45046.4	$ 6431.0	$ 51477.4	$ 394350.7	$ 342873.3
7	$ 49268.8	$ 6816.8	$ 56085.6	$ 418011.7	$ 361926.1
8	$ 53896.4	$ 7225.8	$ 61122.3	$ 443092.4	$ 381970.1
9	$ 58968.9	$ 7659.4	$ 66628.3	$ 469678.0	$ 403049.7
10	$ 64529.6	$ 8119.0	$ 72648.5	$ 497858.6	$ 425210.1
11	$ 70626.1	$ 8606.1	$ 79232.2	$ 527730.2	$ 448497.9
12	$ 77311.0	$ 9122.5	$ 86433.4	$ 559394.0	$ 472960.5
13	$ 84641.6	$ 9669.8	$ 94311.5	$ 592957.6	$ 498646.2
14	$ 92681.3	$ 10250.0	$ 102931.3	$ 628535.1	$ 525603.7
15	$ 101499.5	$ 10865.0	$ 112364.5	$ 666247.2	$ 553882.6
	$ 872206.5	$ 111855.0	$ 1482839.5	$ 6859004.0	$ 5376164.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 5.376 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  2.526 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .492 MILLION LBS
TOTAL NITROGEN EXPENDED       =  3.127 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

6% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST               OPERATING COST
  EQUIP AND MATL= $  275821.00          LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00          LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00          POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00          LN2 RATE  =  .041 $/LB
                     ----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA                 SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK              HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                  NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR              SHUTTLE LAUNCH = 2122.0 GAL/LOADING
                                          DEWAR LOADING  = 8848.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR             TOTAL          = 214084.1 LB/YEAR
  OPERATING LABOR=  6.00                LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00              OPERATIONAL PARAMETERS
  POWER          = 10.00                PERCENT DOWN TIME               =  1.0%
  LIQ NITROGEN   = 10.00                NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  6.00
```

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 26656.8	$ 4805.6	$ 530240.4	$ 374647.1	$ -155593.3
2	$ 29111.6	$ 5093.9	$ 34205.5	$ 397125.9	$ 362920.4
3	$ 31799.1	$ 5399.6	$ 37198.7	$ 420953.5	$ 383754.8
4	$ 34742.0	$ 5723.5	$ 40465.6	$ 446210.7	$ 405745.1
5	$ 37965.0	$ 6067.0	$ 44031.9	$ 472983.4	$ 428951.4
6	$ 41495.2	$ 6431.0	$ 47926.1	$ 501362.4	$ 453436.2
7	$ 45362.4	$ 6816.8	$ 52179.2	$ 531444.1	$ 479264.9
8	$ 49599.4	$ 7225.8	$ 56825.2	$ 563330.7	$ 506505.5
9	$ 54242.1	$ 7659.4	$ 61901.5	$ 597130.6	$ 535229.0
10	$ 59330.1	$ 8119.0	$ 67449.1	$ 632958.4	$ 565509.3
11	$ 64906.8	$ 8606.1	$ 73512.9	$ 670935.9	$ 597423.1
12	$ 71019.7	$ 9122.5	$ 80142.1	$ 711192.1	$ 631049.9
13	$ 77721.2	$ 9669.8	$ 87391.0	$ 753863.6	$ 666472.6
14	$ 85068.9	$ 10250.0	$ 95318.9	$ 799095.4	$ 703776.6
15	$ 93125.8	$ 10865.0	$ 103990.8	$ 847041.1	$ 743050.3
	$ 802146.1	$ 111855.0	$ 1412779.1	$ 8720275.0	$ 7307495.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 7.307 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.211 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  1.230 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.321 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

6% H_2 ESCALATION RATE

```
     -- LIFE CYCLE COST ------SYSTEM 2  NO VENTING
 FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  470965.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                   -----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 2696.0 GAL/LOADING
                                         DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  243613.7 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  6.00

------------------------- CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  693922.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 51862.7	$ 4805.6	$ 750590.3	$ 426324.0	$ -324266.3
2	$ 56829.1	$ 5093.9	$ 61923.0	$ 451903.4	$ 389980.4
3	$ 62278.8	$ 5399.6	$ 67678.4	$ 479017.6	$ 411339.3
4	$ 68259.5	$ 5723.5	$ 73983.1	$ 507758.7	$ 433775.6
5	$ 74823.5	$ 6067.0	$ 80890.5	$ 538224.2	$ 457333.7
6	$ 82028.2	$ 6431.0	$ 88459.2	$ 570517.7	$ 482058.5
7	$ 89936.7	$ 6816.8	$ 96753.5	$ 604748.7	$ 507995.2
8	$ 98618.3	$ 7225.8	$ 105844.2	$ 641033.7	$ 535189.5
9	$ 108149.4	$ 7659.4	$ 115808.8	$ 679495.7	$ 563686.9
10	$ 118613.8	$ 8119.0	$ 126732.7	$ 720265.4	$ 593532.7
11	$ 130103.6	$ 8606.1	$ 138709.7	$ .63481.4	$ 624771.7
12	$ 142720.0	$ 9122.5	$ 151842.5	$ 809290.2	$ 657447.8
13	$ 156574.5	$ 9669.8	$ 166244.3	$ 857847.6	$ 691603.4
14	$ 171789.3	$ 10250.0	$ 182039.3	$ 909318.5	$ 727279.2
15	$ 188499.1	$ 10865.0	$ 199364.1	$ 963877.6	$ 764513.5
	$ 1601086.5	$ 111855.0	$ 2406863.5	$ 9923104.6	$ 7516241.1

```
     PAY BACK OCCURS DURING YEAR  3
     NET SAVINGS OVER 15 YEARS = 7.516 MILLION DOLLARS

     -------------- IN 15 YEARS ------------------
     TOTAL H2 SAVED WITH SYSTEM    =  3.654 MILLION LBS
     TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
     TOTAL H2 VENTED BY SYSTEM     =  0.     MILLION LBS
     TOTAL NITROGEN EXPENDED       =  7.059 MILLION LBS
     TOTAL WATER EXPENDED          = 25.344 MILLION GALS
     TOTAL POWER EXPENDED          = 16.919 MILLION KW-HR
```

6% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 2 5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 6.00

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 3326.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 251025.5 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50954.8	$ 4805.6	$ 749682.4	$ 439294.7	$ -310387.7
2	$ 55830.3	$ 5093.9	$ 60924.3	$ 465652.4	$ 404728.1
3	$ 61180.2	$ 5399.6	$ 66579.8	$ 493591.5	$ 427011.7
4	$ 67051.1	$ 5723.5	$ 72774.7	$ 523207.0	$ 450432.3
5	$ 73494.2	$ 6067.0	$ 79561.2	$ 554599.4	$ 475038.2
6	$ 80566.0	$ 6431.0	$ 86997.0	$ 587875.4	$ 500878.4
7	$ 88328.2	$ 6816.8	$ 95145.1	$ 623147.9	$ 528002.8
8	$ 96849.0	$ 7225.8	$ 104074.9	$ 660536.8	$ 556461.9
9	$ 106203.2	$ 7659.4	$ 113862.6	$ 700169.0	$ 586306.4
10	$ 116473.0	$ 8119.0	$ 124591.9	$ 742179.1	$ 617587.2
11	$ 127748.7	$ 8606.1	$ 136354.7	$ 786709.9	$ 650355.1
12	$ 140129.6	$ 9122.5	$ 149252.1	$ 833912.5	$ 684660.4
13	$ 153725.0	$ 9669.8	$ 163394.8	$ 883947.2	$ 720552.4
14	$ 168654.9	$ 10250.0	$ 178904.9	$ 936984.1	$ 758079.1
15	$ 185051.3	$ 10865.0	$ 195916.3	$ 993203.1	$ 797286.8
	$ 1572239.7	$ 111855.0	$ 2378016.7	$ 10225010.0	$ 7846993.3

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 7.847 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.765 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .104 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.727 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

6% H_2 ESCALATION RATE

```
-- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST               OPERATING COST
  EQUIP AND MATL= $  470965.00          LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00          LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00          POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00          LN2 RATE  =  .041 $/LB
                     ----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                 SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK              HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 3884.0 GAL/LOADING
                                         DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  257590.3 LB/YEAR
  OPERATING LABOR=  6.00                LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00              OPERATIONAL PARAMETERS
  POWER          = 10.00                PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00                NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  6.00
```

------------------------- CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50476.8	$ 4805.6	$ 749204.4	$ 450783.0	$ -298421.4
2	$ 55304.6	$ 5093.9	$ 60398.5	$ 477830.0	$ 417431.5
3	$ 60601.9	$ 5399.6	$ 66001.4	$ 506499.8	$ 440498.4
4	$ 66414.9	$ 5723.5	$ 72138.5	$ 536889.8	$ 464751.3
5	$ 72794.4	$ 6067.0	$ 78861.4	$ 569103.2	$ 490241.8
6	$ 79796.2	$ 6431.0	$ 86227.2	$ 603249.4	$ 517022.2
7	$ 87481.4	$ 6816.8	$ 94298.3	$ 639444.3	$ 545146.0
8	$ 95917.6	$ 7225.8	$ 103143.4	$ 677811.0	$ 574667.6
9	$ 105178.6	$ 7659.4	$ 112838.0	$ 718479.6	$ 605641.6
10	$ 115345.9	$ 8119.0	$ 123464.9	$ 761588.4	$ 638123.6
11	$ 126508.9	$ 8606.1	$ 135115.0	$ 807283.7	$ 672168.8
12	$ 138765.9	$ 9122.5	$ 147888.3	$ 855720.8	$ 707832.4
13	$ 152224.9	$ 9669.8	$ 161894.7	$ 907064.0	$ 745169.3
14	$ 167004.8	$ 10250.0	$ 177254.8	$ 961487.8	$ 784233.0
15	$ 183236.1	$ 10865.0	$ 194101.1	$ 1019177.1	$ 825076.0
	$ 1557052.9	$ 111855.0	$ 2362829.9	$ 10492412.0	$ 8129582.1

PAY BACK OCCURS DURING YEAR 3

NET SAVINGS OVER 15 YEARS = 8.130 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.864 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .209 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.552 MILLION LBS
TOTAL WATER EXPENDED          = 25.344 MILLION GALS
TOTAL POWER EXPENDED          = 16.919 MILLION KW-HR
```

6% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 5374.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 275119.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 6.00

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW ------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 49893.2	$ 4805.6	$ 748620.8	$ 481459.7	$ -267161.1
2	$ 54662.6	$ 5093.9	$ 59756.5	$ 510347.3	$ 450590.8
3	$ 59895.7	$ 5399.6	$ 65295.2	$ 540968.2	$ 475672.9
4	$ 65638.1	$ 5723.5	$ 71361.6	$ 573426.2	$ 502064.6
5	$ 71939.9	$ 6067.0	$ 78006.9	$ 607831.8	$ 529824.9
6	$ 78856.2	$ 6431.0	$ 85287.2	$ 644301.7	$ 559014.5
7	$ 86447.5	$ 6816.8	$ 93264.3	$ 682959.8	$ 589695.5
8	$ 94780.3	$ 7225.8	$ 102006.1	$ 723937.4	$ 621931.3
9	$ 103927.5	$ 7659.4	$ 111586.9	$ 767373.7	$ 655786.7
10	$ 113969.7	$ 8119.0	$ 122088.7	$ 813416.1	$ 691327.4
11	$ 124995.1	$ 8606.1	$ 133601.2	$ 862221.1	$ 728619.9
12	$ 137100.7	$ 9122.5	$ 146223.2	$ 913954.3	$ 767731.2
13	$ 150393.2	$ 9669.8	$ 160063.0	$ 968791.6	$ 808728.5
14	$ 164989.9	$ 10250.0	$ 175239.9	$ 1026919.1	$ 851679.1
15	$ 181019.8	$ 10865.0	$ 191884.8	$ 1088534.2	$ 896649.4
	$ 1538509.5	$ 111855.0	$ 2344286.5	$ 11206442.3	$ 8862155.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 8.862 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 4.127 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .522 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.338 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

10% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE   =  .041 $/LB
                   -----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH =     0.  GAL/LOADING
                                        DEWAR LOADING  =     0.  GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          =  80901.8 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  = 10.00
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 155736.0	$ 127443.7
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 171309.6	$ 140610.8
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 188440.6	$ 155119.9
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 207284.6	$ 171106.9
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 228013.1	$ 188721.1
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 250814.4	$ 208126.9
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 275895.8	$ 229505.3
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 303485.4	$ 253055.5
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 333834.0	$ 278996.6
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 367217.4	$ 307570.1
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 403939.1	$ 339041.3
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 444333.0	$ 373702.5
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 488766.3	$ 411875.2
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 537642.9	$ 453913.3
	$ 632151.2	$ 111855.0	$ 1145212.2	$ 4498290.5	$ 3353078.3

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = 3.353 MILLION DOLLARS

```
------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.214 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.524 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

10% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING

ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  178249.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                    -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  161.8 GAL/LOADING
                                       DEWAR LOADING  =  692.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  90956.0 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  = 10.00
```

------------------------ CASH FLOW ------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20203.1	$ 4805.6	$ 426214.7	$ 159173.0	$ -267041.6
2	$ 22016.8	$ 5093.9	$ 27110.7	$ 175090.3	$ 147979.6
3	$ 23999.5	$ 5399.6	$ 29399.1	$ 192599.4	$ 163200.3
4	$ 26167.4	$ 5723.5	$ 31890.9	$ 211859.3	$ 179968.4
5	$ 28538.1	$ 6067.0	$ 34605.0	$ 233045.2	$ 198440.2
6	$ 31131.1	$ 6431.0	$ 37562.0	$ 256349.8	$ 218787.7
7	$ 33967.7	$ 6816.8	$ 40784.6	$ 281984.7	$ 241200.2
8	$ 37071.5	$ 7225.8	$ 44297.3	$ 310183.2	$ 265885.9
9	$ 40468.0	$ 7659.4	$ 48127.4	$ 341201.5	$ 293074.2
10	$ 44185.5	$ 8119.0	$ 52304.5	$ 375321.7	$ 323017.2
11	$ 48255.1	$ 8606.1	$ 56861.2	$ 412853.9	$ 355992.7
12	$ 52710.6	$ 9122.5	$ 61833.1	$ 454139.3	$ 392306.2
13	$ 57589.5	$ 9669.8	$ 67259.3	$ 499553.2	$ 432293.8
14	$ 62932.8	$ 10250.0	$ 73182.8	$ 549508.5	$ 476325.7
15	$ 68785.5	$ 10865.0	$ 79650.5	$ 604459.3	$ 524808.9
	$ 598022.0	$ 111855.0	$ 1111083.0	$ 5057322.4	$ 3946239.4

PAY BACK OCCURS DURING YEAR 3

NET SAVINGS OVER 15 YEARS = 3.946 MILLION DOLLARS

```
-------------- IN 15 YEARS --------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.364 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .123 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.131 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

10% H_2 ESCALATION RATE

```
    -- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
  ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  178249.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                    -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH =  297.6 GAL/LOADING
                                     DEWAR LOADING  = 1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR        TOTAL          =  99424.3 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  = 10.00

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  401206.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19576.2	$ 4805.6	$ 425587.8	$ 173992.6	$ -251595.2
2	$ 21327.2	$ 5093.9	$ 26421.1	$ 191391.8	$ 164970.7
3	$ 23240.9	$ 5399.6	$ 28640.5	$ 210531.0	$ 181890.5
4	$ 25332.9	$ 5723.5	$ 31056.5	$ 231584.1	$ 200527.6
5	$ 27620.2	$ 6067.0	$ 33687.1	$ 254742.5	$ 221055.4
6	$ 30121.4	$ 6431.0	$ 36552.4	$ 280216.8	$ 243664.4
7	$ 32857.1	$ 6816.8	$ 39673.9	$ 308238.4	$ 268564.5
8	$ 35849.7	$ 7225.8	$ 43075.6	$ 339062.3	$ 295986.7
9	$ 39124.1	$ 7659.4	$ 46783.5	$ 372968.5	$ 326185.0
10	$ 42707.3	$ 8119.0	$ 50826.2	$ 410265.4	$ 359439.2
11	$ 46629.0	$ 8606.1	$ 55235.1	$ 451291.9	$ 396056.8
12	$ 50921.9	$ 9122.5	$ 60044.4	$ 496421.1	$ 436376.7
13	$ 55622.0	$ 9669.8	$ 65291.8	$ 546063.2	$ 480771.4
14	$ 60768.5	$ 10250.0	$ 71018.5	$ 600669.5	$ 529651.1
15	$ 66404.7	$ 10865.0	$ 77269.7	$ 660736.5	$ 583466.8
	$ 578103.0	$ 111855.0	$ 1091164.0	$ 5528175.7	$ 4437011.7

```
     PAY BACK OCCURS DURING YEAR  3
     NET SAVINGS OVER 15 YEARS = 4.437 MILLION DOLLARS

     -------------- IN 15 YEARS -------------------
     TOTAL H2 SAVED WITH SYSTEM    =  1.491 MILLION LBS
     TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
     TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
     TOTAL NITROGEN EXPENDED       =  1.902 MILLION LBS
     TOTAL WATER EXPENDED          =  8.624 MILLION GALS
     TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

10% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00) $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF  =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =  654.8 GAL/LOADING
                                         DEWAR LOADING  = 2769.6 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  121189.2 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME            =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  = 10.00
```

----------------------- CASH FLOW -------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 18758.3	$ 4805.6	$ 424769.9	$ 212081.1	$ -212688.8
2	$ 20427.5	$ 5093.9	$ 25521.5	$ 233289.2	$ 207767.7
3	$ 22251.3	$ 5399.6	$ 27650.9	$ 256618.1	$ 228967.2
4	$ 24244.3	$ 5723.5	$ 29967.9	$ 282280.0	$ 252312.1
5	$ 26422.7	$ 6067.0	$ 32489.7	$ 310508.0	$ 278018.3
6	$ 28804.2	$ 6431.0	$ 35235.2	$ 341558.7	$ 306323.6
7	$ 31408.2	$ 6816.8	$ 38225.0	$ 375714.6	$ 337489.6
8	$ 34256.0	$ 7225.8	$ 41481.8	$ 413286.1	$ 371804.3
9	$ 37370.9	$ 7659.4	$ 45030.3	$ 454614.7	$ 409584.3
10	$ 40778.8	$ 8119.0	$ 48897.7	$ 500076.2	$ 451178.4
11	$ 44507.7	$ 8606.1	$ 53113.8	$ 550083.8	$ 496970.0
12	$ 48588.5	$ 9122.5	$ 57710.9	$ 605092.2	$ 547381.2
13	$ 53055.2	$ 9669.8	$ 62725.0	$ 665601.4	$ 602876.4
14	$ 57945.0	$ 10250.0	$ 68195.0	$ 732161.5	$ 663966.5
15	$ 63298.9	$ 10865.0	$ 74163.9	$ 805377.7	$ 731213.8
	$ 552117.5	$ 111855.0	$ 1065178.5	$ 6738343.1	$ 5673164.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 5.673 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.818 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .615 MILLION LBS
TOTAL NITROGEN EXPENDED       =  1.603 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

10% H_2 ESCALATION RATE

```
  -- LIFE CYCLE COST ------SYSTEM 1  NO VENTING
 TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST          OPERATING COST
  EQUIP AND MATL= $  275821.00     LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00     LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00     POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00     LN2 RATE   =  .041 $/LB
                    -----------    WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA            SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK         HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH =  747.0 GAL/LOADING
                                     DEWAR LOADING  = 2988.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR        TOTAL          =  128965.7 LB/YEAR
  OPERATING LABOR=  6.00           LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00         OPERATIONAL PARAMETERS
  POWER          = 10.00           PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00           NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00           NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  = 10.00

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  498778.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32533.4	$ 4805.6	$ 536117.0	$ 225690.0	$ -310427.0
2	$ 35575.8	$ 5093.9	$ 40669.7	$ 248259.0	$ 207589.3
3	$ 38909.8	$ 5399.6	$ 44309.3	$ 273084.9	$ 228775.6
4	$ 42563.7	$ 5723.5	$ 48287.3	$ 300393.4	$ 252106.2
5	$ 46568.9	$ 6067.0	$ 52635.8	$ 330432.8	$ 277797.0
6	$ 50959.4	$ 6431.0	$ 57390.4	$ 363476.1	$ 306085.7
7	$ 55773.1	$ 6816.8	$ 62589.9	$ 399823.7	$ 337233.8
8	$ 61051.2	$ 7225.8	$ 68277.0	$ 439806.0	$ 371529.0
9	$ 66839.1	$ 7659.4	$ 74498.5	$ 483786.6	$ 409288.2
10	$ 73186.8	$ 8119.0	$ 81305.7	$ 532165.3	$ 450859.6
11	$ 80149.1	$ 8506.1	$ 88755.2	$ 585381.8	$ 496626.7
12	$ 87786.2	$ 9122.5	$ 96908.7	$ 643920.0	$ 547011.4
13	$ 96164.4	$ 9669.8	$ 105834.2	$ 708312.0	$ 602477.8
14	$ 105356.4	$ 10250.0	$ 115606.4	$ 779143.2	$ 663536.9
15	$ 115442.1	$ 10865.0	$ 126307.1	$ 857057.6	$ 730750.5
	$ 988859.2	$ 111855.0	$ 1599492.2	$ 7170732.7	$ 5571240.5

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 5.571 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.934 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  4.471 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

10% H_2 ESCALATION RATE

```
    -- LIFE CYCLE COST ------SYSTEM 1  5% VENTING
  TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  275821.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                     ----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =   500.00 $/YEAR          SHUTTLE LAUNCH = 1095.4 GAL/LOADING
                                       DEWAR LOADING  = 4484.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  150674.1 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME            =  1.0%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  = 10.00

------------------------ CASH FLOW ---------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  498778.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30338.3	$ 4805.6	$ 533921.9	$ 263679.8	$ -270242.1
2	$ 33161.2	$ 5093.9	$ 38255.1	$ 290047.7	$ 251792.6
3	$ 36253.7	$ 5399.6	$ 41653.3	$ 319052.5	$ 277399.2
4	$ 39642.0	$ 5723.5	$ 45365.6	$ 350957.8	$ 305592.2
5	$ 43355.0	$ 6067.0	$ 49422.0	$ 386053.5	$ 336631.6
6	$ 47424.2	$ 6431.0	$ 53855.2	$ 424658.9	$ 370803.7
7	$ 51984.3	$ 6816.8	$ 58701.1	$ 467124.8	$ 408423.6
8	$ 56773.5	$ 7225.8	$ 63999.4	$ 513837.3	$ 449837.9
9	$ 62133.7	$ 7659.4	$ 69793.1	$ 565221.0	$ 495427.9
10	$ 68010.8	$ 8119.0	$ 76129.8	$ 621743.1	$ 545613.3
11	$ 74455.5	$ 8606.1	$ 83061.6	$ 683917.4	$ 600855.8
12	$ 81523.3	$ 9122.5	$ 90645.8	$ 752309.1	$ 661663.3
13	$ 89275.2	$ 9669.8	$ 98945.0	$ 827540.0	$ 728595.0
14	$ 97778.3	$ 10250.0	$ 108028.3	$ 910294.0	$ 802265.8
15	$ 107106.2	$ 10865.0	$ 117971.2	$ 1001323.4	$ 883352.3
	$ 919115.2	$ 111855.0	$ 1529748.2	$ 8377760.2	$ 6848012.1

```
      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 6.848 MILLION DOLLARS

      -------------- IN 15 YEARS -------------------
      TOTAL H2 SAVED WITH SYSTEM    =  2.260 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
      TOTAL NITROGEN EXPENDED       =  3.668 MILLION LBS
      TOTAL WATER EXPENDED          = 14.082 MILLION GALS
      TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

10% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST          OPERATING COST
  EQUIP AND MATL= $  275821.00     LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00     LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00     POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00     LN2 RATE  =  .041 $/LB
                   -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA            SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK         HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR            NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR        SHUTTLE LAUNCH = 1382.0 GAL/LOADING
                                    DEWAR LOADING  = 5704.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR       TOTAL          = 168389.6 LB/YEAR
  OPERATING LABOR=  6.00           LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00         OPERATIONAL PARAMETERS
  POWER          = 10.00           PERCENT DOWN TIME            =  1.0%
  LIQ NITROGEN   = 10.00           NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00           NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  = 10.00
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 28861.9	$ 4805.6	$ 532445.5	$ 294681.8	$ -237763.7
2	$ 31537.1	$ 5093.9	$ 36631.1	$ 324149.9	$ 287518.9
3	$ 34467.3	$ 5399.6	$ 39866.8	$ 356564.9	$ 316698.1
4	$ 37677.0	$ 5723.5	$ 43400.5	$ 392221.4	$ 348820.9
5	$ 41193.4	$ 6067.0	$ 47260.4	$ 431443.6	$ 384183.2
6	$ 45046.4	$ 6431.0	$ 51477.4	$ 474587.9	$ 423110.5
7	$ 49268.8	$ 6816.8	$ 56085.6	$ 522046.7	$ 465961.1
8	$ 53896.4	$ 7225.8	$ 61122.3	$ 574251.4	$ 513129.1
9	$ 58968.9	$ 7659.4	$ 66628.3	$ 631676.5	$ 565048.2
10	$ 64529.6	$ 8119.0	$ 72648.5	$ 694844.2	$ 622195.7
11	$ 70626.1	$ 8606.1	$ 79232.2	$ 764328.6	$ 685096.4
12	$ 77311.0	$ 9122.5	$ 86433.4	$ 840761.5	$ 754328.0
13	$ 84641.6	$ 9669.8	$ 94311.5	$ 924637.6	$ 830526.2
14	$ 92681.3	$ 10250.0	$ 102931.3	$ 1017321.4	$ 914390.0
15	$ 101499.5	$ 10865.0	$ 112364.5	$ 1119053.5	$ 1006689.0
	$ 872206.5	$ 111855.0	$ 1482839.5	$ 9362771.1	$ 7879931.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 7.880 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

```
TOTAL H2 SAVED WITH SYSTEM   =  2.526 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM    =   .492 MILLION LBS
TOTAL NITROGEN EXPENDED      =  3.127 MILLION LBS
TOTAL WATER EXPENDED         = 14.082 MILLION GALS
TOTAL POWER EXPENDED         =  9.400 MILLION KW-HR
```

ORIGINAL PAGE IS
OF POOR QUALITY

10% H_2 ESCALATION RATE


```
   -- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
 TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  275821.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                     -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH = 2122.0 GAL/LOADING
                                       DEWAR LOADING  = 8848.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          = 214084.1 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  = 10.00
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 26656.8	$ 4805.6	$ 530240.4	$ 374647.1	$ -155593.3
2	$ 29111.6	$ 5093.9	$ 34205.5	$ 412111.8	$ 377906.3
3	$ 31799.1	$ 5399.6	$ 37198.7	$ 453323.0	$ 416124.3
4	$ 34742.0	$ 5723.5	$ 40465.6	$ 498655.3	$ 458189.7
5	$ 37965.0	$ 6067.0	$ 44031.9	$ 548520.8	$ 504488.9
6	$ 41495.2	$ 6431.0	$ 47926.1	$ 603372.9	$ 555446.8
7	$ 45362.4	$ 6816.8	$ 52179.2	$ 663710.2	$ 611531.0
8	$ 49599.4	$ 7225.8	$ 56825.2	$ 730081.2	$ 673256.0
9	$ 54242.1	$ 7659.4	$ 61901.5	$ 803089.4	$ 741187.8
10	$ 59330.1	$ 8119.0	$ 67449.1	$ 883398.3	$ 815949.2
11	$ 64906.8	$ 8606.1	$ 73512.9	$ 971738.1	$ 898225.3
12	$ 71019.7	$ 9122.5	$ 80142.1	$ 1068911.9	$ 988769.8
13	$ 77721.2	$ 9669.8	$ 87391.0	$ 1175603.1	$ 1088412.1
14	$ 85068.9	$ 10250.0	$ 95318.9	$ 1293383.4	$ 1198064.6
15	$ 93125.8	$ 10865.0	$ 103990.8	$ 1422721.8	$ 1318731.0
	$ 802146.1	$ 111855.0	$ 1412779.1	$ 11903468.6	$ 10490689.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS =10.491 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.211 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  1.230 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.321 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

10% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  470965.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                   -----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 2696.0 GAL/LOADING
                                         DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  243613.7 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME            =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  = 10.00
```

------------------------ CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 51862.7	$ 4805.6	$ 750590.3	$ 426324.0	$ -324266.3
2	$ 56829.1	$ 5093.9	$ 61923.0	$ 468956.4	$ 407033.4
3	$ 62278.8	$ 5399.6	$ 67678.4	$ 515852.0	$ 448173.7
4	$ 68259.5	$ 5723.5	$ 73983.1	$ 567437.2	$ 493454.1
5	$ 74823.5	$ 6067.0	$ 80890.5	$ 624181.0	$ 543290.5
6	$ 82028.2	$ 6431.0	$ 88459.2	$ 686599.1	$ 598139.9
7	$ 89936.7	$ 6816.8	$ 96753.5	$ 755259.0	$ 658505.5
8	$ 98618.3	$ 7225.8	$ 105844.2	$ 830784.9	$ 724940.7
9	$ 108149.4	$ 7659.4	$ 115808.8	$ 913863.4	$ 798054.5
10	$ 118613.8	$ 8119.0	$ 126732.7	$ 1005249.7	$ 878516.9
11	$ 130103.6	$ 8606.1	$ 138709.7	$ 1105774.7	$ 967065.0
12	$ 142720.0	$ 9122.5	$ 151842.5	$ 1216352.1	$ 1064509.7
13	$ 156574.5	$ 9669.8	$ 166244.3	$ 1337987.3	$ 1171743.1
14	$ 171789.3	$ 10250.0	$ 182039.3	$ 1471786.1	$ 1289746.8
15	$ 188499.1	$ 10865.0	$ 199364.1	$ 1618964.7	$ 1419600.6
	$ 1601086.5	$ 111855.0	$ 2406863.5	$ 13545371.4	$ 11138507.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS =11.139 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM     =  3.654 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED        =  7.059 MILLION LBS
TOTAL WATER EXPENDED           = 25.344 MILLION GALS
TOTAL POWER EXPENDED           = 16.919 MILLION KW-HR
```

10% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 2 5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST		OPERATING COST	
EQUIP AND MATL=	$ 470965.00	LABOR TIME=	8.0 HR/WEEK
DETAILED DESIGN=	$ 47134.00	LABOR RATE=	12.00 $/HR
FABRICATION =	$ 123940.00	POWER RATE=	.024 $/KW-HR
INSTALLATION =	$ 51883.00	LN2 RATE =	.041 $/LB
	-----------	WATER RATE=	.0003 $/GAL
TOTAL * (1.00)	$ 693922.00		

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 10.00

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 3326.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 251025.5 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50954.8	$ 4805.6	$ 749682.4	$ 439294.7	$ -310387.7
2	$ 55830.3	$ 5093.9	$ 60924.3	$ 483224.2	$ 422299.9
3	$ 61180.2	$ 5399.6	$ 66579.8	$ 531546.6	$ 464966.8
4	$ 67051.1	$ 5723.5	$ 72774.7	$ 584701.2	$ 511926.6
5	$ 73494.2	$ 6067.0	$ 79561.2	$ 643171.4	$ 563610.1
6	$ 80566.0	$ 6431.0	$ 86997.0	$ 707488.5	$ 620491.5
7	$ 88328.2	$ 6816.8	$ 95145.1	$ 778237.3	$ 683092.3
8	$ 96849.0	$ 7225.8	$ 104074.9	$ 856061.1	$ 751986.2
9	$ 106203.2	$ 7659.4	$ 113862.6	$ 941667.2	$ 827804.6
10	$ 116473.0	$ 8119.0	$ 124591.9	$ 1035833.9	$ 911242.0
11	$ 127748.7	$ 8606.1	$ 136354.7	$ 1139417.3	$ 1003062.5
12	$ 140129.6	$ 9122.5	$ 149252.1	$ 1253359.0	$ 1104106.9
13	$ 153725.0	$ 9669.8	$ 163394.8	$ 1378694.9	$ 1215300.1
14	$ 168654.9	$ 10250.0	$ 178904.9	$ 1516564.4	$ 1337659.5
15	$ 185051.3	$ 10865.0	$ 195916.3	$ 1668220.9	$ 1472304.6
	$ 1572239.7	$ 111855.0	$ 2378016.7	$ 13957482.5	$ 11579465.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS =11.579 MILLION DOLLARS

------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 3.765 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .104 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.727 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

10% H_2 ESCALATION RATE

```
    -- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
 FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  470965.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                    -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH = 3884.0 GAL/LOADING
                                      DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  257590.3 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR      =  20.0
  LIQ. HYDROGEN  = 10.00

------------------------ CASH FLOW --------------------------------
           TOTAL CAPITAL INVESTMENT COST = $  693922.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50476.8	$ 4805.6	$ 749204.4	$ 450783.0	$ -298421.4
2	$ 55304.6	$ 5093.9	$ 60398.5	$ 495861.3	$ 435462.8
3	$ 60601.9	$ 5399.6	$ 66001.4	$ 545447.5	$ 479446.0
4	$ 66414.9	$ 5723.5	$ 72138.5	$ 599992.2	$ 527853.7
5	$ 72794.4	$ 6067.0	$ 78861.4	$ 659991.4	$ 581130.0
6	$ 79796.2	$ 6431.0	$ 86227.2	$ 725990.6	$ 639763.4
7	$ 87481.4	$ 6816.8	$ 94298.3	$ 798589.6	$ 704291.3
8	$ 95917.6	$ 7225.8	$ 103143.4	$ 878448.6	$ 775305.1
9	$ 105178.6	$ 7659.4	$ 112838.0	$ 966293.4	$ 853455.4
10	$ 115345.9	$ 8119.0	$ 123464.9	$ 1062922.8	$ 939457.9
11	$ 126503.9	$ 8606.1	$ 135115.0	$ 1169215.1	$ 1034100.1
12	$ 138765.9	$ 9122.5	$ 147888.3	$ 1286136.6	$ 1138248.2
13	$ 152224.9	$ 9669.8	$ 161894.7	$ 1414750.2	$ 1252855.5
14	$ 167004.8	$ 10250.0	$ 177254.8	$ 1556225.2	$ 1378970.4
15	$ 183236.1	$ 10865.0	$ 194101.1	$ 1711847.8	$ 1517746.6
	$ 1557052.9	$ 111855.0	$ 2362829.9	$ 14322495.2	$ 11959665.3

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS =11.960 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.864 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .209 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.552 MILLION LBS
TOTAL WATER EXPENDED          = 25.344 MILLION GALS
TOTAL POWER EXPENDED          = 16.919 MILLION KW-HR
```

10% H_2 ESCALATION RATE

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 5374.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 275119.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 10.00

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 49893.2	$ 4805.6	$ 748620.8	$ 481459.7	$ -267161.1
2	$ 54662.6	$ 5093.9	$ 59756.5	$ 529605.7	$ 469849.2
3	$ 59895.7	$ 5399.6	$ 65295.2	$ 582566.3	$ 517271.0
4	$ 65638.1	$ 5723.5	$ 71361.6	$ 640822.9	$ 569461.3
5	$ 71939.9	$ 6067.0	$ 78006.9	$ 704905.2	$ 626898.3
6	$ 78856.2	$ 6431.0	$ 85287.2	$ 775395.7	$ 690108.5
7	$ 86447.5	$ 6816.8	$ 93264.3	$ 852935.3	$ 759670.9
8	$ 94780.3	$ 7225.8	$ 102006.1	$ 938228.8	$ 836222.7
9	$ 103927.5	$ 7659.4	$ 111586.9	$ 1032051.7	$ 920464.8
10	$ 113969.7	$ 8119.0	$ 122088.7	$ 1135256.9	$ 1013168.2
11	$ 124995.1	$ 8606.1	$ 133601.2	$ 1248782.6	$ 1115181.4
12	$ 137100.7	$ 9122.5	$ 146223.2	$ 1373660.8	$ 1227437.7
13	$ 150393.2	$ 9669.8	$ 160063.0	$ 1511026.9	$ 1350963.9
14	$ 164989.9	$ 10250.0	$ 175239.9	$ 1662129.6	$ 1486889.6
15	$ 181019.8	$ 10865.0	$ 191884.8	$ 1828342.5	$ 1636457.7
	$ 1538509.5	$ 111855.0	$ 2344286.5	$ 15297170.6	$ 12952884.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS =12.953 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 4.127 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .522 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.338 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

```
-- LIFE CYCLE COST ------SYSTEM 1  NO VENTING
ONE COMPRESSOR, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE   =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH =     0.  GAL/LOADING
                                        DEWAR LOADING  =     0.  GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          =  80901.8 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME               =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  15.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  15.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  401206.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
	$ 632151.2	$ 111855.0	$ 1145212.2	$ 2123672.9	$ 978460.7

```
PAY BACK OCCURS DURING YEAR  4
NET SAVINGS OVER 15 YEARS =  .978 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM     =  1.214 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  5.131 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED        =  2.524 MILLION LBS
TOTAL WATER EXPENDED           =  8.624 MILLION GALS
TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
```

```
-- LIFE CYCLE COST ------SYSTEM 1  5% VENTING
ONE COMPRESSOR, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST          OPERATING COST
  EQUIP AND MATL= $  178249.00     LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00     LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00     POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00     LN2 RATE  =  .041 $/LB
                    ----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA            SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK         HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH =  161.8 GAL/LOADING
                                     DEWAR LOADING  =  692.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR        TOTAL          =  88442.5 LB/YEAR
  OPERATING LABOR=  6.00           LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00         OPERATIONAL PARAMETERS
  POWER          = 10.00           PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00           NO. OF SHUTTLE LAUNCHES/YEAR=  15.0
  WATER          =  6.00           NO. OF DEWAR LOADINGS/YR    =  15.0
  LIQ. HYDROGEN  =  0.

----------------------- CASH FLOW -------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  401206.00

YEAR OPERATING   MAINTENANCE   TOTAL COST   GROSS SAVINGS   NET SAVINGS
       COST         COST

  1 $  20471.6  $   4305.6  $ 426483.2  $  154774.3   $ -271708.9
  2 $  22312.2  $   5093.9  $  27406.1  $  154774.3   $  127368.2
  3 $  24324.5  $   5399.6  $  29724.0  $  154774.3   $  125050.3
  4 $  26524.8  $   5723.5  $  32248.3  $  154774.3   $  122526.0
  5 $  28931.2  $   6067.0  $  34998.2  $  154774.3   $  119776.1
  6 $  31563.6  $   6431.0  $  37994.5  $  154774.3   $  116779.8
  7 $  34443.5  $   6816.8  $  41260.3  $  154774.3   $  113514.0
  8 $  37594.8  $   7225.8  $  44820.6  $  154774.3   $  109953.7
  9 $  41043.6  $   7659.4  $  48703.0  $  154774.3   $  106071.3
 10 $  44818.7  $   8119.0  $  52937.7  $  154774.3   $  101836.6
 11 $  48951.6  $   8606.1  $  57557.7  $  154774.3   $   97216.6
 12 $  53476.8  $   9122.5  $  62599.3  $  154774.3   $   92175.1
 13 $  58432.3  $   9669.8  $  68102.1  $  154774.3   $   86672.2
 14 $  63859.9  $  10250.0  $  74109.9  $  154774.3   $   80664.4
 15 $  69805.3  $  10865.0  $  80670.3  $  154774.3   $   74104.1
      ---------   ---------   ---------   ----------     ----------
  $  606554.3 $  111855.0 $  1119615.3 $  2321614.9   $  1201999.6

     PAY BACK OCCURS DURING YEAR  4
     NET SAVINGS OVER 15 YEARS = 1.202 MILLION DOLLARS

     ------------- IN 15 YEARS ------------------
     TOTAL H2 SAVED WITH SYSTEM    =  1.327 MILLION LBS
     TOTAL H2 LOST WITH NO SYSTEM  =  5.131 MILLION LBS
     TOTAL H2 VENTED BY SYSTEM     =   .092 MILLION LBS
     TOTAL NITROGEN EXPENDED       =  2.230 MILLION LBS
     TOTAL WATER EXPENDED          =  8.624 MILLION GALS
     TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =   400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =   297.6 GAL/LOADING
                                         DEWAR LOADING  =  1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =   94793.7 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME               =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  15.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  15.0
  LIQ. HYDROGEN  =  0.
```

------------------------- CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20001.4	$ 4805.6	$ 426013.0	$ 165889.0	$ -260124.1
2	$ 21795.0	$ 5093.9	$ 26888.9	$ 165889.0	$ 139000.0
3	$ 23755.5	$ 5399.6	$ 29155.1	$ 165889.0	$ 136733.9
4	$ 25899.0	$ 5723.5	$ 31622.5	$ 165889.0	$ 134266.5
5	$ 28242.8	$ 6067.0	$ 34309.8	$ 165889.0	$ 131579.2
6	$ 30806.3	$ 6431.0	$ 37237.3	$ 165889.0	$ 128651.7
7	$ 33610.5	$ 6816.8	$ 40427.3	$ 165889.0	$ 125461.7
8	$ 36678.5	$ 7225.8	$ 43904.3	$ 165889.0	$ 121984.6
9	$ 40035.7	$ 7659.4	$ 47695.1	$ 165889.0	$ 118193.9
10	$ 43710.0	$ 8119.0	$ 51829.0	$ 165889.0	$ 114060.0
11	$ 47732.0	$ 8606.1	$ 56338.1	$ 165889.0	$ 109550.8
12	$ 52135.3	$ 9122.5	$ 61257.7	$ 165889.0	$ 104631.2
13	$ 56956.7	$ 9669.8	$ 66626.5	$ 165889.0	$ 99262.5
14	$ 62236.6	$ 10250.0	$ 72486.6	$ 165889.0	$ 93402.3
15	$ 68019.7	$ 10865.0	$ 78884.7	$ 165889.0	$ 87004.3
	$ 591615.1	$ 111855.0	$ 1104676.1	$ 2488334.6	$ 1383658.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.384 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.422 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  5.131 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .184 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.058 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

```
 -- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 15 LAUNCHES, 46 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =   500.00 $/YEAR            SHUTTLE LAUNCH =  654.8 GAL/LOADING
                                         DEWAR LOADING  = 2769.6 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  111117.4 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  15.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  15.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW --------------------------------
        TOTAL CAPITAL INVESTMENT COST = $  401206.00

YEAR OPERATING   MAINTENANCE   TOTAL COST   GROSS SAVINGS   NET SAVINGS
       COST         COST

  1 $  19388.0  $   4805.6   $ 425399.6  $  194455.4     $ -230944.3
  2 $  21120.3  $   5093.9   $  26214.2  $  194455.4     $  168241.2
  3 $  23013.3  $   5399.6   $  28412.9  $  194455.4     $  166042.5
  4 $  25082.5  $   5723.5   $  30806.1  $  194455.4     $  163649.3
  5 $  27344.7  $   6067.0   $  33411.7  $  194455.4     $  161043.7
  6 $  29818.4  $   6431.0   $  36249.4  $  194455.4     $  158206.0
  7 $  32523.8  $   6816.8   $  39340.6  $  194455.4     $  155114.7
  8 $  35483.2  $   7225.8   $  42709.0  $  194455.4     $  151746.4
  9 $  38720.9  $   7659.4   $  46380.2  $  194455.4     $  148075.1
 10 $  42263.7  $   8119.0   $  50382.6  $  194455.4     $  144072.7
 11 $  46141.0  $   8606.1   $  54747.1  $  194455.4     $  139708.2
 12 $  50385.2  $   9122.5   $  59507.7  $  194455.4     $  134947.7
 13 $  55031.6  $   9669.8   $  64701.4  $  194455.4     $  129754.0
 14 $  60119.0  $  10250.0   $  70369.0  $  194455.4     $  124086.3
 15 $  65690.3  $  10865.0   $  76555.3  $  194455.4     $  117900.1
     ---------   ---------    ----------   ----------      ----------
  $  572125.9 $  111855.0 $  1085186.9 $  2916830.7    $  1831643.7

      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 1.832 MILLION DOLLARS

      -------------- IN 15 YEARS -------------------
      TOTAL H2 SAVED WITH SYSTEM    =  1.667 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM  =  5.131 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =   .461 MILLION LBS
      TOTAL NITROGEN EXPENDED       =  1.833 MILLION LBS
      TOTAL WATER EXPENDED          =  8.624 MILLION GALS
      TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
TWO COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 275821.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 498778.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

ESCALATION RATES, PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 747.0 GAL/LOADING
  - DEWAR LOADING = 2988.0 GAL/LOADING
  - TOTAL = 117980.4 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 15.0
- NO. OF DEWAR LOADINGS/YR = 15.0

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 29926.8	$ 4805.6	$ 533510.4	$ 206465.6	$ -327044.8
2	$ 32709.6	$ 5093.9	$ 37803.5	$ 206465.6	$ 168662.1
3	$ 35758.0	$ 5399.6	$ 41157.5	$ 206465.6	$ 165308.1
4	$ 39097.9	$ 5723.5	$ 44821.4	$ 206465.6	$ 161644.2
5	$ 42757.6	$ 6067.0	$ 48824.6	$ 206465.6	$ 157641.0
6	$ 46768.3	$ 6431.0	$ 53199.3	$ 206465.6	$ 153266.3
7	$ 51164.2	$ 6816.8	$ 57981.1	$ 206465.6	$ 148484.6
8	$ 55982.8	$ 7225.8	$ 63208.7	$ 206465.6	$ 143256.9
9	$ 61265.4	$ 7659.4	$ 68924.8	$ 206465.6	$ 137540.8
10	$ 67057.4	$ 8119.0	$ 75176.3	$ 206465.6	$ 131289.3
11	$ 73408.4	$ 8606.1	$ 82014.5	$ 206465.6	$ 124451.1
12	$ 80373.3	$ 9122.5	$ 89495.8	$ 206465.6	$ 116969.9
13	$ 88012.1	$ 9669.8	$ 97681.9	$ 206465.6	$ 108783.7
14	$ 96390.9	$ 10250.0	$ 106640.9	$ 206465.6	$ 99824.8
15	$ 105582.1	$ 10865.0	$ 116447.1	$ 206465.6	$ 90018.5
	$ 906254.9	$ 111855.0	$ 1516887.9	$ 3096984.3	$ 1580096.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.580 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM	= 1.770	MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	= 5.131	MILLION LBS
TOTAL H2 VENTED BY SYSTEM	= 0.	MILLION LBS
TOTAL NITROGEN EXPENDED	= 4.016	MILLION LBS
TOTAL WATER EXPENDED	= 12.827	MILLION GALS
TOTAL POWER EXPENDED	= 8.563	MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 1095.4 GAL/LOADING
DEWAR LOADING = 4484.8 GAL/LOADING
TOTAL = 134261.7 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 15.0
NO. OF DEWAR LOADINGS/YR = 15.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 28280.5	$ 4805.6	$ 531864.1	$ 234957.9	$ -296906.2
2	$ 30898.6	$ 5093.9	$ 35992.5	$ 234957.9	$ 198965.4
3	$ 33765.9	$ 5399.6	$ 39165.5	$ 234957.9	$ 195792.4
4	$ 36906.6	$ 5723.5	$ 42630.2	$ 234957.9	$ 192327.7
5	$ 40347.2	$ 6067.0	$ 46414.2	$ 234957.9	$ 188543.7
6	$ 44116.9	$ 6431.0	$ 50547.9	$ 234957.9	$ 184410.0
7	$ 48247.6	$ 6816.8	$ 55064.5	$ 234957.9	$ 179893.4
8	$ 52774.6	$ 7225.8	$ 60000.5	$ 234957.9	$ 174957.5
9	$ 57736.4	$ 7659.4	$ 65395.8	$ 234957.9	$ 169562.1
10	$ 63175.4	$ 8119.0	$ 71294.4	$ 234957.9	$ 163663.5
11	$ 69138.3	$ 8606.1	$ 77744.4	$ 234957.9	$ 157213.5
12	$ 75676.1	$ 9122.5	$ 84798.6	$ 234957.9	$ 150159.3
13	$ 82845.2	$ 9669.8	$ 92515.0	$ 234957.9	$ 142442.9
14	$ 90707.3	$ 10250.0	$ 100957.3	$ 234957.9	$ 134000.6
15	$ 99330.2	$ 10865.0	$ 110195.2	$ 234957.9	$ 124762.7
	$ 853946.9	$ 111855.0	$ 1464579.9	$ 3524368.6	$ 2059788.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.060 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 2.014 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 5.131 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .184 MILLION LBS
TOTAL NITROGEN EXPENDED = 3.414 MILLION LBS
TOTAL WATER EXPENDED = 12.827 MILLION GALS
TOTAL POWER EXPENDED = 8.563 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
TWO COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 1382.0 GAL/LOADING
DEWAR LOADING = 5704.0 GAL/LOADING
TOTAL = 147548.2 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 15.0
NO. OF DEWAR LOADINGS/YR = 15.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 27173.2	$ 4805.6	$ 530756.8	$ 258209.4	$ -272547.4
2	$ 29680.6	$ 5093.9	$ 34774.5	$ 258209.4	$ 223434.9
3	$ 32426.1	$ 5399.6	$ 37825.7	$ 258209.4	$ 220383.8
4	$ 35432.8	$ 5723.5	$ 41156.4	$ 258209.4	$ 217053.1
5	$ 38726.0	$ 6067.0	$ 44793.0	$ 258209.4	$ 213416.4
6	$ 42333.6	$ 6431.0	$ 48764.6	$ 258209.4	$ 209444.8
7	$ 46286.0	$ 6816.8	$ 53102.8	$ 258209.4	$ 205106.6
8	$ 50616.8	$ 7225.8	$ 57842.6	$ 258209.4	$ 200366.8
9	$ 55362.8	$ 7659.4	$ 63022.2	$ 258209.4	$ 195187.2
10	$ 60564.5	$ 8119.0	$ 68683.4	$ 258209.4	$ 189526.0
11	$ 66266.2	$ 8606.1	$ 74872.3	$ 258209.4	$ 183337.1
12	$ 72516.9	$ 9122.5	$ 81639.3	$ 258209.4	$ 176570.1
13	$ 79370.0	$ 9669.8	$ 89039.8	$ 258209.4	$ 169169.6
14	$ 86884.6	$ 10250.0	$ 97134.6	$ 258209.4	$ 161074.8
15	$ 95125.3	$ 10865.0	$ 105990.3	$ 258209.4	$ 152219.2
	$ 818765.4	$ 111855.0	$ 1429398.4	$ 3873141.3	$ 2443742.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.444 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 2.213 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 5.131 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .369 MILLION LBS
TOTAL NITROGEN EXPENDED = 3.009 MILLION LBS
TOTAL WATER EXPENDED = 12.827 MILLION GALS
TOTAL POWER EXPENDED = 8.563 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

ORIGINAL PAGE IS
OF POOR QUALITY

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2122.0 GAL/LOADING
DEWAR LOADING = 8848.0 GAL/LOADING
TOTAL = 181819.1 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 15.0
NO. OF DEWAR LOADINGS/YR = 15.0

------------------------ CASH FLOW ---------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 25519.4	$ 4805.6	$ 529103.0	$ 318183.4	$ -210919.6
2	$ 27861.4	$ 5093.9	$ 32955.3	$ 318183.4	$ 285228.1
3	$ 30425.0	$ 5399.6	$ 35824.6	$ 318183.4	$ 282358.9
4	$ 33231.6	$ 5723.5	$ 38955.1	$ 318183.4	$ 279228.3
5	$ 36304.7	$ 6067.0	$ 42371.7	$ 318183.4	$ 275811.8
6	$ 39670.1	$ 6431.0	$ 46101.1	$ 318183.4	$ 272082.3
7	$ 43356.2	$ 6816.8	$ 50173.0	$ 318183.4	$ 268010.4
8	$ 47394.0	$ 7225.8	$ 54619.9	$ 318183.4	$ 263563.6
9	$ 51817.7	$ 7659.4	$ 59477.1	$ 318183.4	$ 258706.3
10	$ 56664.9	$ 8119.0	$ 64783.9	$ 318183.4	$ 253399.6
11	$ 61976.7	$ 8606.1	$ 70582.8	$ 318183.4	$ 247600.6
12	$ 67798.4	$ 9122.5	$ 76920.9	$ 318183.4	$ 241262.6
13	$ 74179.7	$ 9669.8	$ 83849.5	$ 318183.4	$ 234333.9
14	$ 81175.2	$ 10250.0	$ 91425.2	$ 318183.4	$ 226758.2
15	$ 88845.0	$ 10865.0	$ 99710.0	$ 318183.4	$ 218473.5
	$ 766220.1	$ 111855.0	$ 1376853.1	$ 4772751.4	$ 3395898.3

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.396 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 2.727 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 5.131 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .922 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.404 MILLION LBS
TOTAL WATER EXPENDED = 12.827 MILLION GALS
TOTAL POWER EXPENDED = 8.563 MILLION KW-HR

```
     -- LIFE CYCLE COST ------SYSTEM 2  NO VENTING
  FOUR COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST          OPERATING COST
  EQUIP AND MATL= $  470965.00     LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00     LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00     POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00     LN2 RATE  =  .041 $/LB
                    -----------    WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA            SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK         HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH = 2696.0 GAL/LOADING
                                     DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR        TOTAL          =  203966.3 LB/YEAR
  OPERATING LABOR=  6.00           LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00         OPERATIONAL PARAMETERS
  POWER          = 10.00           PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00           NO. OF SHUTTLE LAUNCHES/YEAR=  15.0
  WATER          =  6.00           NO. OF DEWAR LOADINGS/YR    =  15.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW ---------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  693922.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 44423.8	$ 4805.6	$ 743151.4	$ 356941.1	$ -386210.3
2	$ 48649.5	$ 5093.9	$ 53743.4	$ 356941.1	$ 303197.6
3	$ 53284.8	$ 5399.6	$ 58684.3	$ 356941.1	$ 298256.8
4	$ 58369.7	$ 5723.5	$ 64093.3	$ 356941.1	$ 292847.8
5	$ 63948.6	$ 6067.0	$ 70015.6	$ 356941.1	$ 286925.5
6	$ 70069.9	$ 6431.0	$ 76500.9	$ 356941.1	$ 280440.2
7	$ 76786.9	$ 6816.8	$ 83603.7	$ 356941.1	$ 273337.3
8	$ 84158.2	$ 7225.8	$ 91384.1	$ 356941.1	$ 265557.0
9	$ 92248.2	$ 7659.4	$ 99907.6	$ 356941.1	$ 257033.5
10	$ 101127.6	$ 8119.0	$ 109246.6	$ 356941.1	$ 247694.5
11	$ 110874.3	$ 8606.1	$ 119480.4	$ 356941.1	$ 237460.7
12	$ 121573.6	$ 9122.5	$ 130696.1	$ 356941.1	$ 226245.0
13	$ 133319.6	$ 9669.8	$ 142989.5	$ 356941.1	$ 213951.6
14	$ 146215.6	$ 10250.0	$ 156465.6	$ 356941.1	$ 200475.5
15	$ 160374.9	$ 10865.0	$ 171239.9	$ 356941.1	$ 185701.2
	$ 1365425.4	$ 111855.0	$ 2171202.4	$ 5354116.4	$ 3182914.0

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 3.183 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.059 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  5.131 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  5.957 MILLION LBS
TOTAL WATER EXPENDED          = 21.274 MILLION GALS
TOTAL POWER EXPENDED          = 14.202 MILLION KW-HR
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     -- LIFE CYCLE COST ------SYSTEM 2  5% VENTING
 FOUR COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  470965.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE   =  .041 $/LB
                     ----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH = 3326.0 GAL/LOADING
                                       DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  209525.2 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  15.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR     =  15.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
         TOTAL CAPITAL INVESTMENT COST = $  693922.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 43742.9	$ 4805.6	$ 742470.5	$ 366669.1	$ -375801.4
2	$ 47900.5	$ 5093.9	$ 52994.4	$ 366669.1	$ 313674.7
3	$ 52460.8	$ 5399.6	$ 57860.4	$ 366669.1	$ 308808.7
4	$ 57463.4	$ 5723.5	$ 63187.0	$ 366669.1	$ 303482.1
5	$ 62951.7	$ 6067.0	$ 69018.6	$ 366669.1	$ 297650.5
6	$ 68973.3	$ 6431.0	$ 75404.2	$ 366669.1	$ 291264.9
7	$ 75580.6	$ 6816.8	$ 82397.4	$ 366669.1	$ 284271.7
8	$ 82831.3	$ 7225.8	$ 90057.1	$ 366669.1	$ 276612.0
9	$ 90788.5	$ 7659.4	$ 98447.9	$ 366669.1	$ 268221.2
10	$ 99522.0	$ 8119.0	$ 107641.0	$ 366669.1	$ 259028.1
11	$ 109108.1	$ 8606.1	$ 117714.2	$ 366669.1	$ 248954.9
12	$ 119630.8	$ 9122.5	$ 128753.3	$ 366669.1	$ 237915.8
13	$ 131182.6	$ 9669.8	$ 140852.4	$ 366669.1	$ 225816.7
14	$ 143864.8	$ 10250.0	$ 154114.8	$ 366669.1	$ 212554.3
15	$ 157789.1	$ 10865.0	$ 168654.1	$ 366669.1	$ 198015.1
	$ 1343790.3	$ 111855.0	$ 2149567.3	$ 5500036.6	$ 3350469.3

```
      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 3.350 MILLION DOLLARS

      -------------- IN 15 YEARS ------------------
      TOTAL H2 SAVED WITH SYSTEM    =  3.143 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM  =  5.131 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =   .078 MILLION LBS
      TOTAL NITROGEN EXPENDED       =  5.708 MILLION LBS
      TOTAL WATER EXPENDED          = 21.274 MILLION GALS
      TOTAL POWER EXPENDED          = 14.202 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 3884.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 214448.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 15.0
NO. OF DEWAR LOADINGS/YR = 15.0

------------------------- CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 43384.4	$ 4805.6	$ 742112.0	$ 375285.4	$ -366826.6
2	$ 47506.1	$ 5093.9	$ 52600.1	$ 375285.4	$ 322685.3
3	$ 52027.0	$ 5399.6	$ 57426.6	$ 375285.4	$ 317858.7
4	$ 56986.3	$ 5723.5	$ 62709.8	$ 375285.4	$ 312575.5
5	$ 62426.8	$ 6067.0	$ 68493.8	$ 375285.4	$ 306791.6
6	$ 68395.9	$ 6431.0	$ 74826.9	$ 375285.4	$ 300458.5
7	$ 74945.5	$ 6816.8	$ 81762.3	$ 375285.4	$ 293523.0
8	$ 82132.7	$ 7225.8	$ 89358.5	$ 375285.4	$ 285926.8
9	$ 90020.1	$ 7659.4	$ 97679.5	$ 375285.4	$ 277605.9
10	$ 98676.7	$ 8119.0	$ 106795.7	$ 375285.4	$ 268489.7
11	$ 108178.3	$ 8606.1	$ 116784.4	$ 375285.4	$ 258501.0
12	$ 118608.0	$ 9122.5	$ 127730.5	$ 375285.4	$ 247554.9
13	$ 130057.5	$ 9669.8	$ 139727.3	$ 375285.4	$ 235558.1
14	$ 142627.2	$ 10250.0	$ 152877.2	$ 375285.4	$ 222408.2
15	$ 156427.7	$ 10865.0	$ 167292.7	$ 375285.4	$ 207992.7
	$ 1332400.2	$ 111855.0	$ 2138177.2	$ 5629280.3	$ 3491103.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.491 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.217 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 5.131 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .157 MILLION LBS
TOTAL NITROGEN EXPENDED = 5.577 MILLION LBS
TOTAL WATER EXPENDED = 21.274 MILLION GALS
TOTAL POWER EXPENDED = 14.202 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 15 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 470965.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 693922.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 5374.0 GAL/LOADING
  - DEWAR LOADING =10784.0 GAL/LOADING
  - TOTAL = 227595.9 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 15.0
- NO. OF DEWAR LOADINGS/YR = 15.0

------------------------ CASH FLOW ----------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 42946.7	$ 4805.6	$ 741674.3	$ 398292.9	$ -343381.4
2	$ 47024.6	$ 5093.9	$ 52118.6	$ 398292.9	$ 346174.3
3	$ 51497.4	$ 5399.6	$ 56897.0	$ 398292.9	$ 341395.9
4	$ 56403.7	$ 5723.5	$ 62127.2	$ 398292.9	$ 336165.7
5	$ 61785.9	$ 6067.0	$ 67852.9	$ 398292.9	$ 330440.0
6	$ 67690.9	$ 6431.0	$ 74121.9	$ 398292.9	$ 324171.0
7	$ 74170.0	$ 6816.8	$ 80986.9	$ 398292.9	$ 317306.0
8	$ 81279.7	$ 7225.8	$ 88505.5	$ 398292.9	$ 309787.4
9	$ 89081.8	$ 7659.4	$ 96741.2	$ 398292.9	$ 301551.7
10	$ 97644.6	$ 8119.0	$ 105763.5	$ 398292.9	$ 292529.3
11	$ 107042.9	$ 8606.1	$ 115649.0	$ 398292.9	$ 282643.9
12	$ 117359.2	$ 9122.5	$ 126481.6	$ 398292.9	$ 271811.3
13	$ 128683.7	$ 9669.8	$ 138353.5	$ 398292.9	$ 259939.4
14	$ 141116.0	$ 10250.0	$ 151366.0	$ 398292.9	$ 246926.9
15	$ 154765.4	$ 10865.0	$ 165630.4	$ 398292.9	$ 232662.5
	$ 1318492.6	$ 111855.0	$ 2124269.6	$ 5974393.4	$ 3850123.8

PAY BACK OCCURS DURING YEAR 3

NET SAVINGS OVER 15 YEARS = 3.850 MILLION DOLLARS

-------------- IN 15 YEARS -------------------

- TOTAL H2 SAVED WITH SYSTEM = 3.414 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 5.131 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = .391 MILLION LBS
- TOTAL NITROGEN EXPENDED = 5.417 MILLION LBS
- TOTAL WATER EXPENDED = 21.274 MILLION GALS
- TOTAL POWER EXPENDED = 14.202 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
ONE COMPRESSOR, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 178249.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 401206.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

ESCALATION RATES, PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 0. GAL/LOADING
  - DEWAR LOADING = 0. GAL/LOADING
  - TOTAL = 80901.8 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 5.8%
- NO. OF SHUTTLE LAUNCHES/YEAR= 25.0
- NO. OF DEWAR LOADINGS/YR = 25.0

------------------------ CASH FLOW ------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8506.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
	$ 632151.2	$ 111855.0	$ 1145212.2	$ 2123672.9	$ 978460.7

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = .978 MILLION DOLLARS

-------------- IN 15 YEARS --------------
- TOTAL H2 SAVED WITH SYSTEM = 1.214 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 7.693 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
- TOTAL NITROGEN EXPENDED = 2.524 MILLION LBS
- TOTAL WATER EXPENDED = 8.624 MILLION GALS
- TOTAL POWER EXPENDED = 5.758 MILLION KW-HR

```
-- LIFE CYCLE COST ------SYSTEM 1  5% VENTING
ONE COMPRESSOR, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  178249.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                   -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH =  161.8 GAL/LOADING
                                      DEWAR LOADING  =  692.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  93469.6 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  25.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR    =  25.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  401206.00
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YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19934.5	$ 4805.6	$ 425946.1	$ 163571.7	$ -262374.4
2	$ 21721.4	$ 5093.9	$ 26815.3	$ 163571.7	$ 136756.4
3	$ 23674.6	$ 5399.6	$ 29074.2	$ 163571.7	$ 134497.6
4	$ 25809.9	$ 5723.5	$ 31533.5	$ 163571.7	$ 132038.3
5	$ 28144.9	$ 6067.0	$ 34211.8	$ 163571.7	$ 129359.9
6	$ 30698.6	$ 6431.0	$ 37129.5	$ 163571.7	$ 126442.2
7	$ 33492.0	$ 6816.8	$ 40308.8	$ 163571.7	$ 123262.9
8	$ 36548.1	$ 7225.8	$ 43774.0	$ 163571.7	$ 119797.8
9	$ 39892.3	$ 7659.4	$ 47551.7	$ 163571.7	$ 116020.0
10	$ 43552.3	$ 8119.0	$ 51671.3	$ 163571.7	$ 111900.5
11	$ 47558.5	$ 8606.1	$ 56164.6	$ 163571.7	$ 107407.1
12	$ 51944.4	$ 9122.5	$ 61066.9	$ 163571.7	$ 102504.9
13	$ 56746.7	$ 9669.8	$ 66416.5	$ 163571.7	$ 97155.2
14	$ 62005.7	$ 10250.0	$ 72255.7	$ 163571.7	$ 91316.0
15	$ 67765.7	$ 10865.0	$ 78630.7	$ 163571.7	$ 84941.1
	$ 589489.7	$ 111855.0	$ 1102550.7	$ 2453576.2	$ 1351025.5

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 1.351 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.402 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .154 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.033 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

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 -- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 25 LAUNCHES, 46 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  178249.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                    -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  297.6 GAL/LOADING
                                       DEWAR LOADING  = 1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  104055.0 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME             =  5.8%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  25.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR      =  25.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
        TOTAL CAPITAL INVESTMENT COST = $  401206.00

YEAR OPERATING  MAINTENANCE  TOTAL COST  GROSS SAVINGS  NET SAVINGS
       COST        COST

  1 $  19150.9 $    4805.6   $ 425162.5 $   182096.2   $ -243066.3
  2 $  20859.4 $    5093.9   $  25953.3 $   182096.2   $  156142.8
  3 $  22726.4 $    5399.6   $  28125.9 $   182096.2   $  153970.2
  4 $  24766.9 $    5723.5   $  30490.4 $   182096.2   $  151605.7
  5 $  26997.5 $    6067.0   $  33064.5 $   182096.2   $  149031.7
  6 $  29436.5 $    6431.0   $  35867.5 $   182096.2   $  146228.7
  7 $  32103.7 $    6816.8   $  38920.5 $   182096.2   $  143175.7
  8 $  35021.0 $    7225.8   $  42246.9 $   182096.2   $  139849.3
  9 $  38212.5 $    7659.4   $  45871.9 $   182096.2   $  136224.3
 10 $  41704.5 $    8119.0   $  49823.4 $   182096.2   $  132272.7
 11 $  45525.9 $    8606.1   $  54132.0 $   182096.2   $  127964.1
 12 $  49708.6 $    9122.5   $  58831.0 $   182096.2   $  123265.1
 13 $  54287.3 $    9669.8   $  63957.1 $   182096.2   $  118139.1
 14 $  59300.3 $   10250.0   $  69550.3 $   182096.2   $  112545.8
 15 $  64789.7 $   10865.0   $  75654.7 $   182096.2   $  106441.4
     ---------   ---------   ----------   ----------     ----------
  $  564591.0 $  111855.0 $  1077652.0 $  2731442.4   $  1653790.5

       PAY BACK OCCURS DURING YEAR  3
       NET SAVINGS OVER 15 YEARS = 1.654 MILLION DOLLARS

       ------------- IN 15 YEARS ------------------
       TOTAL H2 SAVED WITH SYSTEM    =  1.561 MILLION LBS
       TOTAL H2 LOST WITH NO SYSTEM  =  7.693 MILLION LBS
       TOTAL H2 VENTED BY SYSTEM     =   .307 MILLION LBS
       TOTAL NITROGEN EXPENDED       =  1.746 MILLION LBS
       TOTAL WATER EXPENDED          =  8.624 MILLION GALS
       TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
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-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

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CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  178249.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                   -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  654.8 GAL/LOADING
                                       DEWAR LOADING  = 2769.6 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  131261.1 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  25.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR     =  25.0
  LIQ. HYDROGEN  =  0.
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------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 18128.6	$ 4805.6	$ 424140.2	$ 229706.8	$ -194433.3
2	$ 19734.8	$ 5093.9	$ 24828.8	$ 229706.8	$ 204878.1
3	$ 21489.3	$ 5399.6	$ 26888.9	$ 229706.8	$ 202817.9
4	$ 23406.2	$ 5723.5	$ 29129.7	$ 229706.8	$ 200577.1
5	$ 25500.7	$ 6067.0	$ 31567.7	$ 229706.8	$ 198139.1
6	$ 27790.0	$ 6431.0	$ 34221.0	$ 229706.8	$ 195485.9
7	$ 30292.6	$ 6816.8	$ 37109.4	$ 229706.8	$ 192597.4
8	$ 33028.8	$ 7225.8	$ 40254.6	$ 229706.8	$ 189452.2
9	$ 36021.0	$ 7659.4	$ 43680.4	$ 229706.8	$ 186026.4
10	$ 39293.9	$ 8119.0	$ 47412.9	$ 229706.8	$ 182294.0
11	$ 42874.3	$ 8606.1	$ 51480.4	$ 229706.8	$ 178226.5
12	$ 46791.7	$ 9122.5	$ 55914.2	$ 229706.8	$ 173792.6
13	$ 51078.8	$ 9669.8	$ 60748.6	$ 229706.8	$ 168958.3
14	$ 55771.0	$ 10250.0	$ 66021.0	$ 229706.8	$ 163685.9
15	$ 60907.5	$ 10865.0	$ 71772.5	$ 229706.8	$ 157934.4
	$ 532109.1	$ 111855.0	$ 1045170.1	$ 3445602.6	$ 2400432.4

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.400 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM     =  1.969 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =   .769 MILLION LBS
TOTAL NITROGEN EXPENDED        =  1.372 MILLION LBS
TOTAL WATER EXPENDED           =  8.624 MILLION GALS
TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
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    -- LIFE CYCLE COST ------SYSTEM 1  NO VENTING
  TWO COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  275821.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                   -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH =  747.0 GAL/LOADING
                                      DEWAR LOADING  = 2988.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  139951.1 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  25.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR    =  25.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  498778.00

YEAR OPERATING  MAINTENANCE  TOTAL COST  GROSS SAVINGS  NET SAVINGS
       COST        COST

  1 $  35140.0  $   4805.6   $ 538723.6  $  244914.5   $ -293809.1
  2 $  38442.0  $   5093.9   $  43536.0  $  244914.5   $  201378.5
  3 $  42061.6  $   5399.6   $  47461.1  $  244914.5   $  197453.3
  4 $  46029.6  $   5723.5   $  51753.1  $  244914.5   $  193161.3
  5 $  50380.1  $   6067.0   $  56447.1  $  244914.5   $  188467.4
  6 $  55150.5  $   6431.0   $  61581.5  $  244914.5   $  183333.0
  7 $  60381.9  $   6816.8   $  67198.8  $  244914.5   $  177715.7
  8 $  66119.5  $   7225.8   $  73345.3  $  244914.5   $  171569.1
  9 $  72412.7  $   7659.4   $  80072.1  $  244914.5   $  164842.3
 10 $  79316.2  $   8119.0   $  87435.1  $  244914.5   $  157479.3
 11 $  86889.7  $   8606.1   $  95495.8  $  244914.5   $  149418.6
 12 $  95199.1  $   9122.5   $ 104321.6  $  244914.5   $  140592.9
 13 $ 104316.7  $   9669.8   $ 113986.5  $  244914.5   $  130928.0
 14 $ 114321.9  $  10250.0   $ 124571.9  $  244914.5   $  120342.6
 15 $ 125302.0  $  10865.0   $ 136167.0  $  244914.5   $  108747.5
     ---------    ---------   ----------    ----------    ----------
  $ 1071463.5 $  111855.0 $  1682096.5 $  3673716.9   $  1991620.4

      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 1.992 MILLION DOLLARS

      -------------- IN 15 YEARS ------------------
      TOTAL H2 SAVED WITH SYSTEM    =  2.099 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM =  7.693 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =  0.     MILLION LBS
      TOTAL NITROGEN EXPENDED       =  4.925 MILLION LBS
      TOTAL WATER EXPENDED          = 15.337 MILLION GALS
      TOTAL POWER EXPENDED          = 10.237 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 1095.4 GAL/LOADING
DEWAR LOADING = 4484.8 GAL/LOADING
TOTAL = 167086.6 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 25.0
NO. OF DEWAR LOADINGS/YR = 25.0

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32396.1	$ 4805.6	$ 535979.7	$ 292401.6	$ -243578.1
2	$ 35423.8	$ 5093.9	$ 40517.7	$ 292401.6	$ 251883.9
3	$ 38741.5	$ 5399.6	$ 44141.0	$ 292401.6	$ 248260.6
4	$ 42377.5	$ 5723.5	$ 48101.0	$ 292401.6	$ 244300.6
5	$ 46362.8	$ 6067.0	$ 52429.7	$ 292401.6	$ 239971.9
6	$ 50731.5	$ 6431.0	$ 57162.4	$ 292401.6	$ 235239.2
7	$ 55521.0	$ 6816.8	$ 62337.8	$ 292401.6	$ 230063.8
8	$ 60772.4	$ 7225.8	$ 67998.3	$ 292401.6	$ 224403.3
9	$ 66531.0	$ 7659.4	$ 74190.4	$ 292401.6	$ 218211.2
10	$ 72846.3	$ 8119.0	$ 80965.2	$ 292401.6	$ 211436.4
11	$ 79772.8	$ 8606.1	$ 88378.9	$ 292401.6	$ 204022.7
12	$ 87370.5	$ 9122.5	$ 96493.0	$ 292401.6	$ 195908.6
13	$ 95705.2	$ 9669.8	$ 105375.0	$ 292401.6	$ 187026.6
14	$ 104849.2	$ 10250.0	$ 115099.2	$ 292401.6	$ 177302.4
15	$ 114882.1	$ 10865.0	$ 125747.1	$ 292401.6	$ 166654.5
	$ 984283.5	$ 111855.0	$ 1594916.5	$ 4386024.1	$ 2791107.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.791 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 2.506 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .307 MILLION LBS
TOTAL NITROGEN EXPENDED = 3.921 MILLION LBS
TOTAL WATER EXPENDED = 15.337 MILLION GALS
TOTAL POWER EXPENDED = 10.237 MILLION KW-HR

```
    -- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
  TWO COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YL.R LIFE

CAPITAL INVESTMENT COST          OPERATING COST
  EQUIP AND MATL= $  275821.00     LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00     LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00     POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00     LN2 RATE  =  .041 $/LB
                   -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA            SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK         HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH = 1382.0 GAL/LOADIN(
                                     DEWAR LOADING  = 5704.0 GAL/LOADIN(
ESCALATION RATES,PERCENT/YEAR        TOTAL          =  189230.9 LB/YEAR
  OPERATING LABOR=  6.00           LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00         OPERATIONAL PARAMETERS
  POWER          = 10.00           PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00           NO. OF SHUTTLE LAUNCHES/YEAR=  25.0
  WATER          =  6.00           NO. OF DEWAR LOADINGS/YR    =  25.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30550.6	$ 4805.6	$ 534134.2	$ 331154.1	$ -202980.1
2	$ 33393.7	$ 5093.9	$ 38487.6	$ 331154.1	$ 292666.5
3	$ 36508.4	$ 5399.6	$ 41908.0	$ 331154.1	$ 289246.1
4	$ 39921.1	$ 5723.5	$ 45644.7	$ 331154.1	$ 285509.5
5	$ 43660.8	$ 6067.0	$ 49727.7	$ 331154.1	$ 281426.4
6	$ 47759.3	$ 6431.0	$ 54190.3	$ 331154.1	$ 276963.9
7	$ 52251.6	$ 6816.8	$ 59068.4	$ 331154.1	$ 272085.7
8	$ 57176.1	$ 7225.8	$ 64401.9	$ 331154.1	$ 266752.2
9	$ 62575.0	$ 7659.4	$ 70234.4	$ 331154.1	$ 260919.7
10	$ 68494.7	$ 8119.0	$ 76613.6	$ 331154.1	$ 254540.5
11	$ 74986.1	$ 8606.1	$ 83592.2	$ 331154.1	$ 247562.0
12	$ 82105.1	$ 9122.5	$ 91227.6	$ 331154.1	$ 239926.6
13	$ 89913.3	$ 9669.8	$ 99583.1	$ 331154.1	$ 231571.0
14	$ 98478.1	$ 10250.0	$ 108728.1	$ 331154.1	$ 222426.0
15	$ 107873.8	$ 10865.0	$ 118738.8	$ 331154.1	$ 212415.3
	$ 925647.6	$ 111855.0	$ 1536280.6	$ 4967311.8	$ 3431031.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.431 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM   =  2.838 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM    =   .615 MILLION LBS
TOTAL NITROGEN EXPENDED      =  3.246 MILLION LBS
TOTAL WATER EXPENDED         = 15.337 MILLION GALS
TOTAL POWER EXPENDED         = 10.237 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

```
CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  275821.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                    ----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH = 2122.0 GAL/LOADING
                                       DEWAR LOADING  = 8848.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          = 246349.0 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  25.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR      =  25.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 27794.3	$ 4805.6	$ 531377.9	$ 431110.8	$ -100267.1
2	$ 30361.7	$ 5093.9	$ 35455.7	$ 431110.8	$ 395655.1
3	$ 33173.3	$ 5399.6	$ 38572.8	$ 431110.8	$ 392538.0
4	$ 36252.4	$ 5723.5	$ 41976.0	$ 431110.8	$ 389134.8
5	$ 39625.2	$ 6067.0	$ 45692.2	$ 431110.8	$ 385418.6
6	$ 43320.2	$ 6431.0	$ 49751.2	$ 431110.8	$ 381359.6
7	$ 47368.6	$ 6816.8	$ 54185.4	$ 431110.8	$ 376925.4
8	$ 51804.8	$ 7225.8	$ 59030.6	$ 431110.8	$ 372080.2
9	$ 56666.6	$ 7659.4	$ 64325.9	$ 431110.8	$ 366784.9
10	$ 61995.4	$ 8119.0	$ 70114.4	$ 431110.8	$ 360996.5
11	$ 67836.8	$ 8606.1	$ 76442.9	$ 431110.8	$ 354667.9
12	$ 74241.0	$ 9122.5	$ 83363.4	$ 431110.8	$ 347747.4
13	$ 81262.7	$ 9669.8	$ 90932.5	$ 431110.8	$ 340178.3
14	$ 88962.5	$ 10250.0	$ 99212.5	$ 431110.8	$ 331898.3
15	$ 97406.7	$ 10865.0	$ 108271.7	$ 431110.8	$ 322839.1
	$ 838072.1	$ 111855.0	$ 1448705.1	$ 6466662.0	$ 5017956.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 5.018 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM     =  3.695 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =  1.537 MILLION LBS
TOTAL NITROGEN EXPENDED        =  2.238 MILLION LBS
TOTAL WATER EXPENDED           = 15.337 MILLION GALS
TOTAL POWER EXPENDED           = 10.237 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2696.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 283261.1 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 25.0
NO. OF DEWAR LOADINGS/YR = 25.0

------------------------- CASH FLOW ---------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 59301.7	$ 4805.6	$ 758029.3	$ 495706.9	$ -262322.3
2	$ 65008.6	$ 5093.9	$ 70102.5	$ 495706.9	$ 425604.4
3	$ 71272.9	$ 5399.6	$ 76672.4	$ 495706.9	$ 419034.5
4	$ 78149.3	$ 5723.5	$ 83872.9	$ 495706.9	$ 411834.0
5	$ 85698.4	$ 6067.0	$ 91765.4	$ 495706.9	$ 403941.5
6	$ 93986.5	$ 6431.0	$ 100417.5	$ 495706.9	$ 395289.5
7	$ 103086.4	$ 6816.8	$ 109903.3	$ 495706.9	$ 385803.7
8	$ 113078.4	$ 7225.8	$ 120304.3	$ 495706.9	$ 375402.6
9	$ 124050.6	$ 7659.4	$ 131710.0	$ 495706.9	$ 363996.9
10	$ 136099.9	$ 8119.0	$ 144218.9	$ 495706.9	$ 351488.0
11	$ 149332.8	$ 8606.1	$ 157938.9	$ 495706.9	$ 337768.0
12	$ 163866.4	$ 9122.5	$ 172988.8	$ 495706.9	$ 322718.1
13	$ 179829.3	$ 9669.8	$ 189499.1	$ 495706.9	$ 306207.8
14	$ 197363.1	$ 10250.0	$ 207613.1	$ 495706.9	$ 288093.8
15	$ 216623.3	$ 10865.0	$ 227488.3	$ 495706.9	$ 268218.6
	$ 1836747.6	$ 111855.0	$ 2642524.6	$ 7435603.6	$ 4793079.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.793 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 4.249 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
TOTAL NITROGEN EXPENDED = 8.160 MILLION LBS
TOTAL WATER EXPENDED = 29.415 MILLION GALS
TOTAL POWER EXPENDED = 19.635 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 5% VENTING
FOUR COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 3326.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 292525.9 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 25.0
NO. OF DEWAR LOADINGS/YR = 25.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 58166.8	$ 4805.6	$ 756894.4	$ 511920.3	$ -244974.1
2	$ 63760.2	$ 5093.9	$ 68854.2	$ 511920.3	$ 443066.1
3	$ 69899.6	$ 5399.6	$ 75299.2	$ 511920.3	$ 436621.1
4	$ 76638.8	$ 5723.5	$ 82362.3	$ 511920.3	$ 429557.9
5	$ 84036.8	$ 6067.0	$ 90103.8	$ 511920.3	$ 421816.5
6	$ 92158.7	$ 6431.0	$ 98589.7	$ 511920.3	$ 413330.6
7	$ 101075.9	$ 6816.8	$ 107892.7	$ 511920.3	$ 404027.6
8	$ 110866.8	$ 7225.8	$ 118092.7	$ 511920.3	$ 393827.6
9	$ 121617.9	$ 7659.4	$ 129277.3	$ 511920.3	$ 382643.0
10	$ 133423.9	$ 8119.0	$ 141542.9	$ 511920.3	$ 370377.4
11	$ 146389.2	$ 8606.1	$ 154995.3	$ 511920.3	$ 356925.0
12	$ 160628.4	$ 9122.5	$ 169750.8	$ 511920.3	$ 342169.4
13	$ 176267.5	$ 9669.8	$ 185937.3	$ 511920.3	$ 325983.0
14	$ 193445.1	$ 10250.0	$ 203695.1	$ 511920.3	$ 308225.2
15	$ 212313.5	$ 10865.0	$ 223178.5	$ 511920.3	$ 288741.8
	$ 1800689.2	$ 111855.0	$ 2606466.2	$ 7678804.1	$ 5072337.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 5.072 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 4.388 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .130 MILLION LBS
TOTAL NITROGEN EXPENDED = 7.745 MILLION LBS
TOTAL WATER EXPENDED = 29.415 MILLION GALS
TOTAL POWER EXPENDED = 19.635 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

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CAPITAL INVESTMENT COST               OPERATING COST
  EQUIP AND MATL= $  470965.00          LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00          LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00          POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00          LN2 RATE  =  .041 $/LB
                    ----------          WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                 SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK              HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                  NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR              SHUTTLE LAUNCH = 3884.0 GAL/LOADING
                                          DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR             TOTAL          =  300731.8 LB/YEAR
  OPERATING LABOR=  6.00                LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00              OPERATIONAL PARAMETERS
  POWER          = 10.00                PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00                NO. OF SHUTTLE LAUNCHES/YEAR=  25.0
  WATER          =  6.00                NO. OF DEWAR LOADINGS/YR    =  25.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW ------------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 57569.3	$ 4805.6	$ 756296.9	$ 526280.7	$ -230016.2
2	$ 63103.0	$ 5093.9	$ 68196.9	$ 526280.7	$ 458083.8
3	$ 69176.7	$ 5399.6	$ 74576.3	$ 526280.7	$ 451704.4
4	$ 75843.5	$ 5723.5	$ 81567.1	$ 526280.7	$ 444713.6
5	$ 83162.1	$ 6067.0	$ 89229.0	$ 526280.7	$ 437051.7
6	$ 91196.5	$ 6431.0	$ 97627.4	$ 526280.7	$ 428653.2
7	$ 100017.4	$ 6816.8	$ 106834.2	$ 526280.7	$ 419446.4
8	$ 109702.5	$ 7225.8	$ 116928.4	$ 526280.7	$ 409352.3
9	$ 120337.1	$ 7659.4	$ 127996.5	$ 526280.7	$ 398284.2
10	$ 132015.1	$ 8119.0	$ 140134.0	$ 526280.7	$ 386146.6
11	$ 144839.5	$ 8606.1	$ 153445.6	$ 526280.7	$ 372835.1
12	$ 158923.7	$ 9122.5	$ 168046.1	$ 526280.7	$ 358234.5
13	$ 174392.3	$ 9669.8	$ 184062.1	$ 526280.7	$ 342218.5
14	$ 191382.4	$ 10250.0	$ 201632.4	$ 526280.7	$ 324648.3
15	$ 210044.6	$ 10865.0	$ 220909.6	$ 526280.7	$ 305371.1
	$ 1781705.6	$ 111855.0	$ 2587482.6	$ 7894210.2	$ 5306727.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 5.307 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM     =  4.511 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM   =  7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =   .261 MILLION LBS
TOTAL NITROGEN EXPENDED        =  7.527 MILLION LBS
TOTAL WATER EXPENDED           = 29.415 MILLION GALS
TOTAL POWER EXPENDED           = 19.635 MILLION KW-HR
```

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 25 LAUNCHES, 48 HRS 15 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 5374.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 322643.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 25.0
NO. OF DEWAR LOADINGS/YR = 25.0

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 56839.7	$ 4805.6	$ 755567.3	$ 564626.6	$ -190940.8
2	$ 62300.5	$ 5093.9	$ 67394.4	$ 564626.6	$ 497232.1
3	$ 68293.9	$ 5399.6	$ 73693.5	$ 564626.6	$ 490933.1
4	$ 74872.5	$ 5723.5	$ 80596.1	$ 564626.6	$ 484030.5
5	$ 82093.9	$ 6067.0	$ 88160.9	$ 564626.6	$ 476465.7
6	$ 90021.5	$ 6431.0	$ 96452.5	$ 564626.6	$ 468174.1
7	$ 98725.0	$ 6816.8	$ 105541.8	$ 564626.6	$ 459084.8
8	$ 108280.8	$ 7225.8	$ 115506.7	$ 564626.6	$ 449119.9
9	$ 118773.3	$ 7659.4	$ 126432.7	$ 564626.6	$ 438193.9
10	$ 130294.9	$ 8119.0	$ 138413.8	$ 564626.6	$ 426212.7
11	$ 142947.2	$ 8606.1	$ 151553.3	$ 564626.6	$ 413073.2
12	$ 156842.2	$ 9122.5	$ 165964.7	$ 564626.6	$ 398661.9
13	$ 172102.7	$ 9669.8	$ 181772.5	$ 564626.6	$ 382854.0
14	$ 188863.9	$ 10250.0	$ 199113.9	$ 564626.6	$ 365512.7
15	$ 207274.1	$ 10865.0	$ 218139.1	$ 564626.6	$ 346487.4
	$ 1758526.4	$ 111855.0	$ 2564303.4	$ 8469398.6	$ 5905095.3

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 5.905 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 4.840 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 7.693 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .652 MILLION LBS
TOTAL NITROGEN EXPENDED = 7.260 MILLION LBS
TOTAL WATER EXPENDED = 29.415 MILLION GALS
TOTAL POWER EXPENDED = 19.635 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING

ONE COMPRESSOR, 26 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 178249.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 401206.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 0. GAL/LOADING
DEWAR LOADING = 0. GAL/LOADING
TOTAL = 80901.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
	$ 324868.1	$ 63341.6	$ 789415.7	$ 1415781.9	$ 626366.2

PAY BACK OCCURS DURING YEAR 4

NET SAVINGS OVER 10 YEARS = .626 MILLION DOLLARS

------------- IN 10 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM	=	.809 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	=	4.275 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	=	0. MILLION LBS
TOTAL NITROGEN EXPENDED	=	1.683 MILLION LBS
TOTAL WATER EXPENDED	=	5.749 MILLION GALS
TOTAL POWER EXPENDED	=	3.839 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 178249.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 401206.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 161.8 GAL/LOADING
  - DEWAR LOADING = 692.8 GAL/LOADING
  - TOTAL = 90956.0 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 5.8%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20203.1	$ 4805.6	$ 426214.7	$ 159173.0	$ -267041.6
2	$ 22016.8	$ 5093.9	$ 27110.7	$ 159173.0	$ 132062.3
3	$ 23999.5	$ 5399.6	$ 29399.1	$ 159173.0	$ 129773.9
4	$ 26167.4	$ 5723.5	$ 31890.9	$ 159173.0	$ 127282.1
5	$ 28538.1	$ 6067.0	$ 34605.0	$ 159173.0	$ 124568.0
6	$ 31131.1	$ 6431.0	$ 37562.0	$ 159173.0	$ 121611.0
7	$ 33967.7	$ 6816.8	$ 40784.6	$ 159173.0	$ 118388.5
8	$ 37071.5	$ 7225.8	$ 44297.3	$ 159173.0	$ 114875.7
9	$ 40468.0	$ 7659.4	$ 48127.4	$ 159173.0	$ 111045.7
10	$ 44185.5	$ 8119.0	$ 52304.5	$ 159173.0	$ 106868.6
	$ 307748.5	$ 63341.6	$ 772296.2	$ 1591730.4	$ 819434.2

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 10 YEARS = .819 MILLION DOLLARS

-------------- IN 10 YEARS -------------------

TOTAL H2 SAVED WITH SYSTEM	=	.910 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	=	4.275 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	=	.082 MILLION LBS
TOTAL NITROGEN EXPENDED	=	1.421 MILLION LBS
TOTAL WATER EXPENDED	=	5.749 MILLION GALS
TOTAL POWER EXPENDED	=	3.839 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 178249.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 401206.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 297.6 GAL/LOADING
DEWAR LOADING = 1276.8 GAL/LOADING
TOTAL = 99424.3 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19576.2	$ 4805.6	$ 425587.8	$ 173992.6	$ -251595.2
2	$ 21327.2	$ 5093.9	$ 26421.1	$ 173992.6	$ 147571.4
3	$ 23240.9	$ 5399.6	$ 28640.5	$ 173992.6	$ 145352.1
4	$ 25332.9	$ 5723.5	$ 31056.5	$ 173992.6	$ 142936.1
5	$ 27620.2	$ 6067.0	$ 33687.1	$ 173992.6	$ 140305.4
6	$ 30121.4	$ 6431.0	$ 36552.4	$ 173992.6	$ 137440.2
7	$ 32857.1	$ 6816.8	$ 39673.9	$ 173992.6	$ 134318.7
8	$ 35849.7	$ 7225.8	$ 43075.6	$ 173992.6	$ 130917.0
9	$ 39124.1	$ 7659.4	$ 46783.5	$ 173992.6	$ 127209.1
10	$ 42707.3	$ 8119.0	$ 50826.2	$ 173992.6	$ 123166.3
	$ 297757.0	$ 63341.6	$ 762304.6	$ 1739925.7	$ 977621.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 10 YEARS = .978 MILLION DOLLARS

-------------- IN 10 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = .994 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 4.275 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .164 MILLION LBS
TOTAL NITROGEN EXPENDED = 1.268 MILLION LBS
TOTAL WATER EXPENDED = 5.749 MILLION GALS
TOTAL POWER EXPENDED = 3.839 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 178249.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 401206.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 654.8 GAL/LOADING
DEWAR LOADING = 2769.6 GAL/LOADING
TOTAL = 121189.2 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 18758.3	$ 4805.6	$ 424769.9	$ 212081.1	$ -212688.8
2	$ 20427.5	$ 5093.9	$ 25521.5	$ 212081.1	$ 186559.6
3	$ 22251.3	$ 5399.6	$ 27650.9	$ 212081.1	$ 184430.2
4	$ 24244.3	$ 5723.5	$ 29967.9	$ 212081.1	$ 182113.2
5	$ 26422.7	$ 6067.0	$ 32489.7	$ 212081.1	$ 179591.4
6	$ 28804.2	$ 6431.0	$ 35235.2	$ 212081.1	$ 176845.9
7	$ 31408.2	$ 6816.8	$ 38225.0	$ 212081.1	$ 173856.1
8	$ 34256.0	$ 7225.8	$ 41481.8	$ 212081.1	$ 170599.3
9	$ 37370.9	$ 7659.4	$ 45030.3	$ 212081.1	$ 167050.8
10	$ 40778.8	$ 8119.0	$ 48897.7	$ 212081.1	$ 163183.4
	$ 284722.3	$ 63341.6	$ 749270.0	$ 2120811.1	$ 1371541.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 10 YEARS = 1.372 MILLION DOLLARS

-------------- IN 10 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 1.212 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 4.275 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .410 MILLION LBS
TOTAL NITROGEN EXPENDED = 1.069 MILLION LBS
TOTAL WATER EXPENDED = 5.749 MILLION GALS
TOTAL POWER EXPENDED = 3.839 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING

TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST		OPERATING COST	
EQUIP AND MATL=	$ 275821.00	LABOR TIME=	8.0 HR/WEEK
DETAILED DESIGN=	$ 47134.00	LABOR RATE=	12.00 $/HR
FABRICATION =	$ 123940.00	POWER RATE=	.024 $/KW-HR
INSTALLATION =	$ 51883.00	LN2 RATE =	.041 $/LB
	-----------	WATER RATE=	.0003 $/GAL
TOTAL * (1.00)	$ 498778.00		

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 747.0 GAL/LOADING
DEWAR LOADING = 2988.0 GAL/LOADING
TOTAL = 128965.7 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------- CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32533.4	$ 4805.6	$ 536117.0	$ 225690.0	$ -310427.0
2	$ 35575.8	$ 5093.9	$ 40669.7	$ 225690.0	$ 185020.3
3	$ 38909.8	$ 5399.6	$ 44309.3	$ 225690.0	$ 181380.7
4	$ 42563.7	$ 5723.5	$ 48287.3	$ 225690.0	$ 177402.8
5	$ 46568.9	$ 6067.0	$ 52635.8	$ 225690.0	$ 173054.2
6	$ 50959.4	$ 6431.0	$ 57390.4	$ 225690.0	$ 168299.6
7	$ 55773.1	$ 6816.8	$ 62589.9	$ 225690.0	$ 163100.1
8	$ 61051.2	$ 7225.8	$ 68277.0	$ 225690.0	$ 157413.0
9	$ 66839.1	$ 7659.4	$ 74498.5	$ 225690.0	$ 151191.6
10	$ 73186.8	$ 8119.0	$ 81305.7	$ 225690.0	$ 144384.3
	$ 503961.1	$ 63341.6	$ 1066080.7	$ 2256900.4	$ 1190819.7

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 10 YEARS = 1.191 MILLION DOLLARS

-------------- IN 10 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM = 1.290 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 4.275 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
TOTAL NITROGEN EXPENDED = 2.980 MILLION LBS
TOTAL WATER EXPENDED = 9.388 MILLION GALS
TOTAL POWER EXPENDED = 6.267 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

```
CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  275821.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                   -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH = 1095.4 GAL/LOADING
                                        DEWAR LOADING  = 4484.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          = 150674.1 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30338.3	$ 4805.6	$ 533921.9	$ 263679.8	$ -270242.1
2	$ 33161.2	$ 5093.9	$ 38255.1	$ 263679.8	$ 225424.6
3	$ 36253.7	$ 5399.6	$ 41653.3	$ 263679.8	$ 222026.5
4	$ 39642.0	$ 5723.5	$ 45365.6	$ 263679.8	$ 218314.2
5	$ 43355.0	$ 6067.0	$ 49422.0	$ 263679.8	$ 214257.8
6	$ 47424.2	$ 6431.0	$ 53855.2	$ 263679.8	$ 209824.6
7	$ 51884.3	$ 6816.8	$ 58701.1	$ 263679.8	$ 204978.6
8	$ 56773.5	$ 7225.8	$ 63999.4	$ 263679.8	$ 199680.4
9	$ 62133.7	$ 7659.4	$ 69793.1	$ 263679.8	$ 193886.7
10	$ 68010.8	$ 8119.0	$ 76129.8	$ 263679.8	$ 187550.0
	$ 468976.7	$ 63341.6	$ 1031096.3	$ 2636797.6	$ 1605701.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 10 YEARS = 1.606 MILLION DOLLARS

```
-------------- IN 10 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.507 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  4.275 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .164 MILLION LBS
TOTAL NITROGEN EXPENDED       =  2.445 MILLION LBS
TOTAL WATER EXPENDED          =  9.388 MILLION GALS
TOTAL POWER EXPENDED          =  6.267 MILLION KW-HR
```

```
   -- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
 TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST          OPERATING COST
 EQUIP AND MATL= $  275821.00      LABOR TIME=  8.0 HR/WEEK
 DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
 FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
 INSTALLATION   =$   51683.00      LN2 RATE  =  .041 $/LB
                  -----------      WATER RATE= .0003 $/GAL
 TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA            SAVINGS DATA
 LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
 LABOR RATE= 12.00 $/HR             NORMAL BOILOFF =  400.0 GAL/DAY
 MATERIALS =  500.00 $/YEAR         SHUTTLE LAUNCH = 1382.0 GAL/LOADING
                                    DEWAR LOADING  = 5704.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR       TOTAL          =  168389.6 LB/YEAR
 OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
 MAINTEN. LABOR =  6.00
 MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
 POWER          = 10.00            PERCENT DOWN TIME            =  1.0%
 LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
 WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.0
 LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW ----------------------------------
         TOTAL CAPITAL INVESTMENT COST = $  498778.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 28861.9	$ 4805.6	$ 532445.5	$ 294681.8	$ -237763.7
2	$ 31537.1	$ 5093.9	$ 36631.1	$ 294681.8	$ 258050.7
3	$ 34467.3	$ 5399.6	$ 39866.8	$ 294681.8	$ 254814.9
4	$ 37677.0	$ 5723.5	$ 43400.5	$ 294681.8	$ 251281.3
5	$ 41193.4	$ 6067.0	$ 47260.4	$ 294681.8	$ 247421.4
6	$ 45046.4	$ 6431.0	$ 51477.4	$ 294681.8	$ 243204.4
7	$ 49268.8	$ 6816.8	$ 56085.6	$ 294681.8	$ 238596.1
8	$ 53896.4	$ 7225.8	$ 61122.3	$ 294681.8	$ 233559.5
9	$ 58968.9	$ 7659.4	$ 66628.3	$ 294681.8	$ 228053.5
10	$ 64529.6	$ 8119.0	$ 72648.5	$ 294681.8	$ 222033.2
	$ 445446.8	$ 63341.6	$ 1007566.4	$ 2946817.7	$ 1939251.3

```
 PAY BACK OCCURS DURING YEAR  3
 NET SAVINGS OVER 10 YEARS = 1.939 MILLION DOLLARS

 ------------- IN 10 YEARS ------------------
 TOTAL H2 SAVED WITH SYSTEM   =  1.684 MILLION LBS
 TOTAL H2 LOST WITH NO SYSTEM =  4.275 MILLION LBS
 TOTAL H2 VENTED BY SYSTEM    =   .328 MILLION LBS
 TOTAL NITROGEN EXPENDED      =  2.085 MILLION LBS
 TOTAL WATER EXPENDED         =  9.388 MILLION GALS
 TOTAL POWER EXPENDED         =  6.267 MILLION KW-HR
```

```
    -- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
  TWO COMPRESSORS, 25 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  275821.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$    47134.00     LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$    51883.00     LN2 RATE  =  .041 $/LB
                   -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  498778.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH = 2122.0 GAL/LOADING
                                      DEWAR LOADING  = 8848.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  214084.1 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW ---------------------------------
        TOTAL CAPITAL INVESTMENT COST = $  498778.00

YEAR OPERATING  MAINTENANCE  TOTAL COST  GROSS SAVINGS  NET SAVINGS
       COST        COST

  1 $  26656.8  $   4805.6   $ 530240.4  $  374647.1    $ -155593.3
  2 $  29111.6  $   5093.9   $  34205.5  $  374647.1    $  340441.6
  3 $  31799.1  $   5399.6   $  37198.7  $  374647.1    $  337448.4
  4 $  34742.0  $   5723.5   $  40465.6  $  374647.1    $  334181.6
  5 $  37965.0  $   6067.0   $  44031.9  $  374647.1    $  330615.2
  6 $  41495.2  $   6431.0   $  47926.1  $  374647.1    $  326721.0
  7 $  45362.4  $   6816.8   $  52179.2  $  374647.1    $  322467.9
  8 $  49599.4  $   7225.8   $  56825.2  $  374647.1    $  317821.9
  9 $  54242.1  $   7659.4   $  61901.5  $  374647.1    $  312745.6
 10 $  59330.1  $   8119.0   $  67449.1  $  374647.1    $  307198.0
     ---------    ---------    ---------    ----------     ----------
   $  410303.7 $   63341.6 $   972423.4 $  3746471.1   $  2774047.8

      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 10 YEARS = 2.774 MILLION DOLLARS

      ------------- IN 10 YEARS ------------------
      TOTAL H2 SAVED WITH SYSTEM    =  2.141 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM =  4.275 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =   .820 MILLION LBS
      TOTAL NITROGEN EXPENDED       =  1.547 MILLION LBS
      TOTAL WATER EXPENDED          =  9.388 MILLION GALS
      TOTAL POWER EXPENDED          =  6.267 MILLION KW-HR
```

```
-- LIFE CYCLE COST ------SYSTEM 2  NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  470965.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                   -----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 2696.0 GAL/LOADING
                                         DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  243613.7 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
         TOTAL CAPITAL INVESTMENT COST = $  693922.00

YEAR OPERATING   MAINTENANCE   TOTAL COST  GROSS SAVINGS  NET SAVINGS
        COST         COST

  1 $  51862.7  $    4805.6   $ 750590.3  $   426324.0    $ -324266.3
  2 $  56829.1  $    5093.9   $  61923.0  $   426324.0    $  364401.0
  3 $  62278.8  $    5399.6   $  67678.4  $   426324.0    $  358645.6
  4 $  68259.5  $    5723.5   $  73983.1  $   426324.0    $  352340.9
  5 $  74823.5  $    6067.0   $  80890.5  $   426324.0    $  345433.5
  6 $  82028.2  $    6431.0   $  88459.2  $   426324.0    $  337864.8
  7 $  89936.7  $    6816.8   $  96753.5  $   426324.0    $  329570.5
  8 $  98618.3  $    7225.8   $ 105844.2  $   426324.0    $  320479.8
  9 $ 108149.4  $    7659.4   $ 115808.8  $   426324.0    $  310515.2
 10 $ 118613.8  $    8119.0   $ 126732.7  $   426324.0    $  299591.3
    ---------   ---------     ----------    ---------     ----------
  $  811400.1 $   63341.6 $   1568663.7 $  4263240.0    $  2694576.3

       PAY BACK OCCURS DURING YEAR  3
       NET SAVINGS OVER 10 YEARS = 2.695 MILLION DOLLARS

       -------------- IN 10 YEARS ------------------
       TOTAL H2 SAVED WITH SYSTEM    =  2.436 MILLION LBS
       TOTAL H2 LOST WITH NO SYSTEM  =  4.275 MILLION LBS
       TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
       TOTAL NITROGEN EXPENDED       =  4.706 MILLION LBS
       TOTAL WATER EXPENDED          = 16.896 MILLION GALS
       TOTAL POWER EXPENDED          = 11.279 MILLION KW-HR
```

```
-- LIFE CYCLE COST ------SYSTEM 2  5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST                 OPERATING COST
  EQUIP AND MATL= $  470965.00            LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00            LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00            POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00            LN2 RATE  =  .041 $/LB
                  -----------             WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA                   SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK                HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                   NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR               SHUTTLE LAUNCH = 3326.0 GAL/LOADING
                                           DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR              TOTAL        =  251025.5 LB/YEAR
  OPERATING LABOR=  6.00                  LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00                OPERATIONAL PARAMETERS
  POWER          = 10.00                  PERCENT DOWN TIME              =   1.0%
  LIQ NITROGEN   = 10.00                  NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                  NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW ---------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  693922.00

YEAR OPERATING  MAINTENANCE  TOTAL COST  GROSS SAVINGS  NET SAVINGS
       COST        COST

  1 $  50954.8  $   4805.6   $ 749682.4  $  439294.7    $ -310387.7
  2 $  55830.3  $   5093.9   $  60924.3  $  439294.7    $  378370.4
  3 $  61180.2  $   5399.6   $  66579.8  $  439294.7    $  372714.9
  4 $  67051.1  $   5723.5   $  72774.7  $  439294.7    $  366520.0
  5 $  73494.2  $   6067.0   $  79561.2  $  439294.7    $  359733.5
  6 $  80566.0  $   6431.0   $  86997.0  $  439294.7    $  352297.7
  7 $  88328.2  $   6816.8   $  95145.1  $  439294.7    $  344149.6
  8 $  96849.0  $   7225.8   $ 104074.9  $  439294.7    $  335219.8
  9 $ 106203.2  $   7659.4   $ 113862.6  $  439294.7    $  325432.1
 10 $ 116473.0  $   8119.0   $ 124591.9  $  439294.7    $  314702.8
     ---------   ---------   ----------   ---------     ----------
  $  796930.2 $   63341.6 $  1554193.8 $  4392946.9   $  2838753.1

       PAY BACK OCCURS DURING YEAR  3
       NET SAVINGS OVER 10 YEARS = 2.839 MILLION DOLLARS

       -------------- IN 10 YEARS ------------------
       TOTAL H2 SAVED WITH SYSTEM    =  2.510 MILLION LBS
       TOTAL H2 LOST WITH NO SYSTEM =  4.275 MILLION LBS
       TOTAL H2 VENTED BY SYSTEM     =   .070 MILLION LBS
       TOTAL NITROGEN EXPENDED       =  4.484 MILLION LBS
       TOTAL WATER EXPENDED          = 16.896 MILLION GALS
       TOTAL POWER EXPENDED          = 11.279 MILLION KW-HR
```

LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

```
CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  470965.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                    -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH = 3884.0 GAL/LOADING
                                       DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  257590.3 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50476.8	$ 4805.6	$ 749204.4	$ 450783.0	$ -298421.4
2	$ 55304.6	$ 5093.9	$ 60398.5	$ 450783.0	$ 390384.5
3	$ 60601.9	$ 5399.6	$ 66001.4	$ 450783.0	$ 384781.6
4	$ 66414.9	$ 5723.5	$ 72138.5	$ 450783.0	$ 378644.6
5	$ 72794.4	$ 6067.0	$ 78861.4	$ 450783.0	$ 371921.6
6	$ 79796.2	$ 6431.0	$ 86227.2	$ 450783.0	$ 364555.9
7	$ 87481.4	$ 6816.8	$ 94298.3	$ 450783.0	$ 356484.7
8	$ 95917.6	$ 7225.8	$ 103143.4	$ 450783.0	$ 347639.6
9	$ 105178.6	$ 7659.4	$ 112838.0	$ 450783.0	$ 337945.0
10	$ 115345.9	$ 8119.0	$ 123464.9	$ 450783.0	$ 327318.2
	$ 789312.3	$ 63341.6	$ 1546575.9	$ 4507830.2	$ 2961254.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 10 YEARS = 2.961 MILLION DOLLARS

```
-------------- IN 10 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  2.576 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  4.275 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .139 MILLION LBS
TOTAL NITROGEN EXPENDED       =  4.368 MILLION LBS
TOTAL WATER EXPENDED          = 16.896 MILLION GALS
TOTAL POWER EXPENDED          = 11.279 MILLION KW-HR
```

C-3

-- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 10 YEAR LIFE

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 470965.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.00) $ 693922.00

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 5374.0 GAL/LOADING
  - DEWAR LOADING =10784.0 GAL/LOADING
  - TOTAL = 275119.8 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW ------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 49893.2	$ 4605.6	$ 748620.8	$ 481459.7	$ -267161.1
2	$ 54662.6	$ 5093.9	$ 59756.5	$ 481459.7	$ 421703.2
3	$ 59895.7	$ 5399.6	$ 65295.2	$ 481459.7	$ 416164.5
4	$ 65638.1	$ 5723.5	$ 71361.6	$ 481459.7	$ 410098.1
5	$ 71939.9	$ 6067.0	$ 78006.9	$ 481459.7	$ 403452.8
6	$ 78856.2	$ 6431.0	$ 85287.2	$ 481459.7	$ 396172.5
7	$ 86447.5	$ 6816.8	$ 93264.3	$ 481459.7	$ 388195.4
8	$ 94780.3	$ 7225.8	$ 102006.1	$ 481459.7	$ 379453.6
9	$ 103927.5	$ 7659.4	$ 111586.9	$ 481459.7	$ 369872.8
10	$ 113969.7	$ 8119.0	$ 122088.7	$ 481459.7	$ 359371.0
	$ 780010.8	$ 63341.6	$ 1537274.4	$ 4814597.3	$ 3277323.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 10 YEARS = 3.277 MILLION DOLLARS

-------------- IN 10 YEARS --------------
- TOTAL H2 SAVED WITH SYSTEM = 2.751 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 4.275 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = .348 MILLION LBS
- TOTAL NITROGEN EXPENDED = 4.226 MILLION LBS
- TOTAL WATER EXPENDED = 16.896 MILLION GALS
- TOTAL POWER EXPENDED = 11.279 MILLION KW-HR

-- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

```
CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  178249.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                     -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =     0.  GAL/LOADING
                                       DEWAR LOADING  =     0.  GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  80901.8 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW -------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 427288.9	$ 141578.2	$ -285710.7
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
16	$ 79684.0	$ 11516.9	$ 91200.9	$ 141578.2	$ 50377.2
17	$ 87157.4	$ 12207.9	$ 99365.3	$ 141578.2	$ 42212.9
18	$ 95348.3	$ 12940.4	$ 108288.7	$ 141578.2	$ 33289.5
19	$ 104326.9	$ 13716.8	$ 118043.7	$ 141578.2	$ 23534.5
20	$ 114169.9	$ 14539.8	$ 128709.8	$ 141578.2	$ 12868.4
	$ 1112837.8	$ 176776.8	$ 1690820.6	$ 2831563.8	$ 1140743.2

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 20 YEARS = 1.141 MILLION DOLLARS

-------------- IN 20 YEARS ------------------

```
TOTAL H2 SAVED WITH SYSTEM    =  1.618 MILLION LBS      TOTAL WATER EXPENDED     = 11.498 MILLION GALS
TOTAL H2 LOST WITH NO SYSTEM  =  8.549 MILLION LBS      TOTAL POWER EXPENDED     =  7.677 MILLION KW-HR
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  3.366 MILLION LBS
```

- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 178249.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 401206.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 161.8 GAL/LOADING
DEWAR LOADING = 692.8 GAL/LOADING
TOTAL = 90956.0 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------- CASH FLOW -------------------------
TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20203.1	$ 4805.6	$ 426214.7	$ 159173.0	$ -267041.6
2	$ 22016.8	$ 5093.9	$ 27110.7	$ 159173.0	$ 132062.3
3	$ 23999.5	$ 5399.6	$ 29399.1	$ 159173.0	$ 129773.9
4	$ 26167.4	$ 5723.5	$ 31890.9	$ 159173.0	$ 127282.1
5	$ 28538.1	$ 6067.0	$ 34605.0	$ 159173.0	$ 124568.0
6	$ 31131.1	$ 6431.0	$ 37562.0	$ 159173.0	$ 121611.0
7	$ 33967.7	$ 6816.8	$ 40784.6	$ 159173.0	$ 118388.5
8	$ 37071.5	$ 7225.8	$ 44297.3	$ 159173.0	$ 114875.7
9	$ 40468.0	$ 7659.4	$ 48127.4	$ 159173.0	$ 111045.7
10	$ 44185.5	$ 8119.0	$ 52304.5	$ 159173.0	$ 106868.6
11	$ 48255.1	$ 8606.1	$ 56861.2	$ 159173.0	$ 102311.9
12	$ 52710.6	$ 9122.5	$ 61833.1	$ 159173.0	$ 97340.0
13	$ 57589.5	$ 9669.8	$ 67259.3	$ 159173.0	$ 91913.7
14	$ 62932.8	$ 10250.0	$ 73182.8	$ 159173.0	$ 85990.2
15	$ 68785.5	$ 10865.0	$ 79650.5	$ 159173.0	$ 79522.6
16	$ 75197.0	$ 11516.9	$ 86713.9	$ 159173.0	$ 72459.2
17	$ 82221.6	$ 12207.9	$ 94429.5	$ 159173.0	$ 64743.5
18	$ 89918.9	$ 12940.4	$ 102859.3	$ 159173.0	$ 56313.7
19	$ 98354.6	$ 13716.8	$ 112071.4	$ 159173.0	$ 47101.7
20	$ 107600.4	$ 14539.8	$ 122140.2	$ 159173.0	$ 37032.8
	$ 1051314.5	$ 176776.8	$ 1629297.3	$ 3183460.8	$ 1554163.5

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 20 YEARS = 1.554 MILLION DOLLARS

-------------- IN 20 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 1.819 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .164 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.842 MILLION LBS
TOTAL WATER EXPENDED = 11.498 MILLION GALS
TOTAL POWER EXPENDED = 7.677 MILLION KW-HR

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LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

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CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                   -----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  401206.00

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =   400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH =   297.6 GAL/LOADING
                                        DEWAR LOADING  =  1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          =   99424.3 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME               =   5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19576.2	$ 4805.6	$ 425587.8	$ 173992.6	$ -251595.2
2	$ 21327.2	$ 5093.9	$ 26421.1	$ 173992.6	$ 147571.4
3	$ 23240.9	$ 5399.6	$ 28640.5	$ 173992.6	$ 145352.1
4	$ 25332.9	$ 5723.5	$ 31056.5	$ 173992.6	$ 142936.1
5	$ 27620.2	$ 6067.0	$ 33687.1	$ 173992.6	$ 140305.4
6	$ 30121.4	$ 6431.0	$ 36552.4	$ 173992.6	$ 137440.2
7	$ 32857.1	$ 6816.8	$ 39673.9	$ 173992.6	$ 134318.7
8	$ 35849.7	$ 7225.8	$ 43075.6	$ 173992.6	$ 130917.0
9	$ 39124.1	$ 7659.4	$ 46783.5	$ 173992.6	$ 127209.1
10	$ 42707.3	$ 8119.0	$ 50826.2	$ 173992.6	$ 123166.3
11	$ 46629.0	$ 8606.1	$ 55235.1	$ 173992.6	$ 118757.5
12	$ 50921.9	$ 9122.5	$ 60044.4	$ 173992.6	$ 113948.2
13	$ 55622.0	$ 9669.8	$ 65291.8	$ 173992.6	$ 108700.8
14	$ 60768.5	$ 10250.0	$ 71018.5	$ 173992.6	$ 102974.1
15	$ 66404.7	$ 10865.0	$ 77269.7	$ 173992.6	$ 96722.9
16	$ 72578.1	$ 11516.9	$ 84095.0	$ 173992.6	$ 89897.5
17	$ 79340.9	$ 12207.9	$ 91548.8	$ 173992.6	$ 82443.8
18	$ 86750.2	$ 12940.4	$ 99690.6	$ 173992.6	$ 74302.0
19	$ 94868.9	$ 13716.8	$ 108585.7	$ 173992.6	$ 65406.8
20	$ 103766.2	$ 14539.8	$ 118306.0	$ 173992.6	$ 55686.6
	$ 1015407.3	$ 176776.8	$ 1593390.1	$ 3479851.4	$ 1886461.3

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 1.886 MILLION DOLLARS

-------------- IN 20 YEARS ------------------

```
TOTAL H2 SAVED WITH SYSTEM   =  1.988 MILLION LBS     TOTAL WATER EXPENDED   = 11.498 MILLION GALS
TOTAL H2 LOST WITH NO SYSTEM =  8.549 MILLION LBS     TOTAL POWER EXPENDED   =  7.677 MILLION KW-HR
TOTAL H2 VENTED BY SYSTEM    =   .328 MILLION LBS
TOTAL NITROGEN EXPENDED      =  2.53[illegible] MILLION LBS
```

- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 178249.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 401206.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 654.8 GAL/LOADING
DEWAR LOADING = 2769.6 GAL/LOADING
TOTAL = 121189.2 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

----------------------- CASH FLOW ------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 401206.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 18758.3	$ 4805.6	$ 424769.9	$ 212081.1	$ -212688.8
2	$ 20427.5	$ 5093.9	$ 25521.5	$ 212081.1	$ 186559.6
3	$ 22251.3	$ 5399.6	$ 27650.9	$ 212081.1	$ 184430.2
4	$ 24244.3	$ 5723.5	$ 29967.9	$ 212081.1	$ 182113.2
5	$ 26422.7	$ 6067.0	$ 32489.7	$ 212081.1	$ 179591.4
6	$ 28804.2	$ 6431.0	$ 35235.2	$ 212081.1	$ 176845.9
7	$ 31408.2	$ 6816.8	$ 38225.0	$ 212081.1	$ 173856.1
8	$ 34256.0	$ 7225.8	$ 41481.8	$ 212081.1	$ 170599.3
9	$ 37370.9	$ 7659.4	$ 45030.3	$ 212081.1	$ 167050.8
10	$ 40778.8	$ 8119.0	$ 48897.7	$ 212081.1	$ 163183.4
11	$ 44507.7	$ 8606.1	$ 53113.8	$ 212081.1	$ 158967.4
12	$ 48588.5	$ 9122.5	$ 57710.9	$ 212081.1	$ 154370.2
13	$ 53055.2	$ 9669.8	$ 62725.0	$ 212081.1	$ 149356.1
14	$ 57945.0	$ 10250.0	$ 68195.0	$ 212081.1	$ 143886.1
15	$ 63298.9	$ 10865.0	$ 74163.9	$ 212081.1	$ 137917.2
16	$ 69161.7	$ 11516.9	$ 80678.6	$ 212081.1	$ 131402.5
17	$ 75582.8	$ 12207.9	$ 87790.7	$ 212081.1	$ 124290.4
18	$ 82616.3	$ 12940.4	$ 95556.7	$ 212081.1	$ 116524.4
19	$ 90321.7	$ 13716.8	$ 104038.5	$ 212081.1	$ 108042.6
20	$ 98764.2	$ 14539.8	$ 113304.0	$ 212081.1	$ 98777.1
	$ 968564.3	$ 176776.8	$ 1546547.1	$ 4241622.2	$ 2695075.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 2.695 MILLION DOLLARS

------------- IN 20 YEARS -----------------
TOTAL H2 SAVED WITH SYSTEM = 2.424 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .820 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.137 MILLION LBS
TOTAL WATER EXPENDED = 11.498 MILLION GALS
TOTAL POWER EXPENDED = 7.677 MILLION KW-HR

— LIFE CYCLE COST ------SYSTEM 1 NO VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 747.0 GAL/LOADING
DEWAR LOADING = 2988.0 GAL/LOADING
TOTAL = 128965.7 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW ------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32533.4	$ 4805.6	$ 536117.0	$ 225690.0	$ -310427.0
2	$ 35575.8	$ 5093.9	$ 40669.7	$ 225690.0	$ 185020.3
3	$ 38909.8	$ 5399.6	$ 44309.3	$ 225690.0	$ 181380.7
4	$ 42563.7	$ 5723.5	$ 48287.3	$ 225690.0	$ 177402.8
5	$ 46568.9	$ 6067.0	$ 52635.8	$ 225690.0	$ 173054.2
6	$ 50959.4	$ 6431.0	$ 57390.4	$ 225690.0	$ 168299.6
7	$ 55773.1	$ 6816.8	$ 62589.9	$ 225690.0	$ 163100.1
8	$ 61051.2	$ 7225.8	$ 68277.0	$ 225690.0	$ 157413.0
9	$ 66839.1	$ 7659.4	$ 74498.5	$ 225690.0	$ 151191.6
10	$ 73186.8	$ 8119.0	$ 81305.7	$ 225690.0	$ 144384.3
11	$ 80149.1	$ 8606.1	$ 88755.2	$ 225690.0	$ 136934.9
12	$ 87786.2	$ 9122.5	$ 96908.7	$ 225690.0	$ 128781.4
13	$ 96164.4	$ 9669.8	$ 105834.2	$ 225690.0	$ 119855.8
14	$ 105356.4	$ 10250.0	$ 115606.4	$ 225690.0	$ 110083.7
15	$ 115442.1	$ 10865.0	$ 126307.1	$ 225690.0	$ 99383.0
16	$ 126509.3	$ 11516.9	$ 138026.2	$ 225690.0	$ 87663.8
17	$ 138654.7	$ 12207.9	$ 150862.7	$ 225690.0	$ 74827.4
18	$ 151984.3	$ 12940.4	$ 164924.7	$ 225690.0	$ 60765.3
19	$ 166614.7	$ 13716.8	$ 180331.6	$ 225690.0	$ 45358.5
20	$ 182674.1	$ 14539.8	$ 197213.9	$ 225690.0	$ 28476.1
	$ 1755296.4	$ 176776.8	$ 2430851.3	$ 4513800.8	$ 2082949.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 2.083 MILLION DOLLARS

-------------- IN 20 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 2.579 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
TOTAL NITROGEN EXPENDED = 5.961 MILLION LBS

TOTAL WATER EXPENDED = 18.776 MILLION GALS
TOTAL POWER EXPENDED = 12.533 MILLION KW-HR

LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 1095.4 GAL/LOADING
DEWAR LOADING = 4484.8 GAL/LOADING
TOTAL = 150674.1 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30338.3	$ 4805.6	$ 533921.9	$ 263679.8	$ -270242.1
2	$ 33161.2	$ 5093.9	$ 38255.1	$ 263679.8	$ 225424.6
3	$ 36253.7	$ 5399.6	$ 41653.3	$ 263679.8	$ 222026.5
4	$ 39642.0	$ 5723.5	$ 45365.6	$ 263679.8	$ 218314.2
5	$ 43355.0	$ 6067.0	$ 49422.0	$ 263679.8	$ 214257.8
6	$ 47424.2	$ 6431.0	$ 53855.2	$ 263679.8	$ 209824.6
7	$ 51884.3	$ 6816.8	$ 58701.1	$ 263679.8	$ 204978.6
8	$ 56773.5	$ 7225.8	$ 63999.4	$ 263679.8	$ 199680.4
9	$ 62133.7	$ 7659.4	$ 69793.1	$ 263679.8	$ 193886.7
10	$ 68010.8	$ 8119.0	$ 76129.8	$ 263679.8	$ 187550.0
11	$ 74455.5	$ 8606.1	$ 83061.6	$ 263679.8	$ 180618.1
12	$ 81523.3	$ 9122.5	$ 90645.8	$ 263679.8	$ 173034.0
13	$ 89275.2	$ 9669.8	$ 98945.0	$ 263679.8	$ 164734.7
14	$ 97778.3	$ 10250.0	$ 108028.3	$ 263679.8	$ 155651.5
15	$ 107106.2	$ 10865.0	$ 117971.2	$ 263679.8	$ 145708.6
16	$ 117339.8	$ 11516.9	$ 128856.7	$ 263679.8	$ 134823.0
17	$ 128568.3	$ 12207.9	$ 140776.2	$ 263679.8	$ 122903.6
18	$ 140889.2	$ 12940.4	$ 153829.6	$ 263679.8	$ 109850.1
19	$ 154410.1	$ 13716.8	$ 168126.9	$ 263679.8	$ 95552.8
20	$ 169249.0	$ 14539.8	$ 183788.8	$ 263679.8	$ 79890.9
	$ 1629571.7	$ 176776.8	$ 2305126.5	$ 5273595.1	$ 2968468.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 2.968 MILLION DOLLARS

-------------- IN 20 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.013 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .328 MILLION LBS
TOTAL NITROGEN EXPENDED = 4.89[illegible] MILLION LBS
TOTAL WATER EXPENDED = 18.776 MILLION GALS
TOTAL POWER EXPENDED = 12.533 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 498778.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 1382.0 GAL/LOADING
DEWAR LOADING = 5704.0 GAL/LOADING
TOTAL = 168389.6 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 28861.9	$ 4805.6	$ 532445.5	$ 294681.8	$ -237763.7
2	$ 31537.1	$ 5093.9	$ 36631.1	$ 294681.8	$ 258050.7
3	$ 34467.3	$ 5399.6	$ 39866.8	$ 294681.8	$ 254814.9
4	$ 37677.0	$ 5723.5	$ 43400.5	$ 294681.8	$ 251281.3
5	$ 41193.4	$ 6067.0	$ 47260.4	$ 294681.8	$ 247421.4
6	$ 45046.4	$ 6431.0	$ 51477.4	$ 294681.8	$ 243204.4
7	$ 49268.8	$ 6816.8	$ 56085.6	$ 294681.8	$ 238596.1
8	$ 53896.4	$ 7225.8	$ 61122.3	$ 294681.8	$ 233559.5
9	$ 58968.9	$ 7659.4	$ 66628.3	$ 294681.8	$ 228053.5
10	$ 64529.6	$ 8119.0	$ 72648.5	$ 294681.8	$ 222033.2
11	$ 70626.1	$ 8606.1	$ 79232.2	$ 294681.8	$ 215449.5
12	$ 77311.0	$ 9122.5	$ 86433.4	$ 294681.8	$ 208248.3
13	$ 84641.6	$ 9669.8	$ 94311.5	$ 294681.8	$ 200370.3
14	$ 92681.3	$ 10250.0	$ 102931.3	$ 294681.8	$ 191750.4
15	$ 101499.5	$ 10865.0	$ 112364.5	$ 294681.8	$ 182317.2
16	$ 111172.6	$ 11516.9	$ 122689.5	$ 294681.8	$ 171992.3
17	$ 121784.3	$ 12207.9	$ 133992.2	$ 294681.8	$ 160689.6
18	$ 133426.8	$ 12940.4	$ 146367.2	$ 294681.8	$ 148314.5
19	$ 146201.5	$ 13716.8	$ 159918.3	$ 294681.8	$ 134763.5
20	$ 160219.5	$ 14539.8	$ 174759.4	$ 294681.8	$ 119922.4
	$ 1545011.2	$ 176776.8	$ 2220566.1	$ 5893635.4	$ 3673069.3

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 3.673 MILLION DOLLARS

-------------- IN 20 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 3.368 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .656 MILLION LBS
TOTAL NITROGEN EXPENDED = 4.170 MILLION LBS
TOTAL WATER EXPENDED = 18.776 MILLION GALS
TOTAL POWER EXPENDED = 12.533 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST

EQUIP AND MATL=	$ 275821.00
DETAILED DESIGN=	$ 47134.00
FABRICATION =	$ 123940.00
INSTALLATION =	$ 51883.00
TOTAL * (1.00)	$ 498778.00

OPERATING COST

LABOR TIME=	8.0 HR/WEEK
LABOR RATE=	12.00 $/HR
POWER RATE=	.024 $/KW-HR
LN2 RATE =	.041 $/LB
WATER RATE=	.0003 $/GAL

MAINTENANCE COST DATA

LABOR TIME=	6.9 HR/WEEK
LABOR RATE=	12.00 $/HR
MATERIALS =	500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED

NORMAL BOILOFF =	400.0 GAL/DAY
SHUTTLE LAUNCH =	2122.0 GAL/LOADING
DEWAR LOADING =	8848.0 GAL/LOADING
TOTAL =	214084.1 LB/YEAR
LIQ HYDROGEN COST=	1.75 $/LB

ESCALATION RATES, PERCENT/YEAR

OPERATING LABOR=	6.00
MAINTEN. LABOR =	6.00
MAINTEN. MATL =	6.00
POWER =	10.00
LIQ NITROGEN =	10.00
WATER =	6.00
LIQ. HYDROGEN =	0.

OPERATIONAL PARAMETERS

PERCENT DOWN TIME =	1.0%
NO. OF SHUTTLE LAUNCHES/YEAR=	20.0
NO. OF DEWAR LOADINGS/YR =	20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 498778.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 26656.8	$ 4805.6	$ 530240.4	$ 374647.1	$ -155593.3
2	$ 29111.6	$ 5093.9	$ 34205.5	$ 374647.1	$ 340441.6
3	$ 31799.1	$ 5399.6	$ 37198.7	$ 374647.1	$ 337448.4
4	$ 34742.0	$ 5723.5	$ 40465.6	$ 374647.1	$ 334181.6
5	$ 37965.0	$ 6067.0	$ 44031.9	$ 374647.1	$ 330615.2
6	$ 41495.2	$ 6431.0	$ 47926.1	$ 374647.1	$ 326721.0
7	$ 45362.4	$ 6816.8	$ 52179.2	$ 374647.1	$ 322467.9
8	$ 49599.4	$ 7225.8	$ 56825.2	$ 374647.1	$ 317821.9
9	$ 54242.1	$ 7659.4	$ 61901.5	$ 374647.1	$ 312745.6
10	$ 59330.1	$ 8119.0	$ 67449.1	$ 374647.1	$ 307198.0
11	$ 64906.8	$ 8606.1	$ 73512.9	$ 374647.1	$ 301134.2
12	$ 71019.7	$ 9122.5	$ 80142.1	$ 374647.1	$ 294505.0
13	$ 77721.2	$ 9669.8	$ 87391.0	$ 374647.1	$ 287256.1
14	$ 85068.9	$ 10250.0	$ 95318.9	$ 374647.1	$ 279328.3
15	$ 93125.8	$ 10865.0	$ 103990.8	$ 374647.1	$ 270656.3
16	$ 101961.5	$ 11516.9	$ 113478.4	$ 374647.1	$ 261168.7
17	$ 111652.1	$ 12207.9	$ 123860.0	$ 374647.1	$ 250787.1
18	$ 122281.4	$ 12940.4	$ 135221.8	$ 374647.1	$ 239425.3
19	$ 133941.5	$ 13716.8	$ 147658.3	$ 374647.1	$ 226988.8
20	$ 146733.6	$ 14539.8	$ 161273.4	$ 374647.1	$ 213373.7
	$ 1418716.1	$ 176776.8	$ 2094271.0	$ 7492942.3	$ 5398671.3

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 5.399 MILLION DOLLARS

-------------- IN 20 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM	= 4.282 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	= 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	= 1.639 MILLION LBS
TOTAL NITROGEN EXPENDED	= 3.094 MILLION LBS
TOTAL WATER EXPENDED	= 18.776 MILLION GALS
TOTAL POWER EXPENDED	= 12.533 MILLION KW-HR

LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

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CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  470965.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE   =  .041 $/LB
                    -----------     WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH = 2696.0 GAL/LOADING
                                      DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  243613.7 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME            =  1.0%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
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------------------------- CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 51862.7	$ 4805.6	$ 750590.3	$ 426324.0	$ -324266.3
2	$ 56829.1	$ 5093.9	$ 61923.0	$ 426324.0	$ 364401.0
3	$ 62278.8	$ 5399.6	$ 67678.4	$ 426324.0	$ 358645.6
4	$ 68259.5	$ 5723.5	$ 73983.1	$ 426324.0	$ 352340.9
5	$ 74823.5	$ 6067.0	$ 80890.5	$ 426324.0	$ 345433.5
6	$ 82028.2	$ 6431.0	$ 88459.2	$ 426324.0	$ 337864.8
7	$ 89936.7	$ 6816.8	$ 96753.5	$ 426324.0	$ 329570.5
8	$ 98618.3	$ 7225.8	$ 105844.2	$ 426324.0	$ 320479.8
9	$ 108149.4	$ 7659.4	$ 115808.8	$ 426324.0	$ 310515.2
10	$ 118613.8	$ 8119.0	$ 126732.7	$ 426324.0	$ 299591.3
11	$ 130103.6	$ 8606.1	$ 138709.7	$ 426324.0	$ 287614.3
12	$ 142720.0	$ 9122.5	$ 151842.5	$ 426324.0	$ 274481.5
13	$ 156574.5	$ 9669.8	$ 166244.3	$ 426324.0	$ 260079.7
14	$ 171789.3	$ 10250.0	$ 182039.3	$ 426324.0	$ 244284.7
15	$ 188499.1	$ 10865.0	$ 199364.1	$ 426324.0	$ 226959.9
16	$ 206851.7	$ 11516.9	$ 218368.6	$ 426324.0	$ 207955.4
17	$ 227009.7	$ 12207.9	$ 239217.7	$ 426324.0	$ 187106.3
18	$ 249152.0	$ 12940.4	$ 262092.3	$ 426324.0	$ 164231.7
19	$ 273474.9	$ 13716.8	$ 287191.7	$ 426324.0	$ 139132.3
20	$ 300194.5	$ 14539.8	$ 314734.3	$ 426324.0	$ 111589.7
	$ 2857769.3	$ 176776.8	$ 3728468.1	$ 8526480.0	$ 4798011.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 4.798 MILLION DOLLARS

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-------------- IN 20 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM     =  4.872 MILLION LBS      TOTAL WATER EXPENDED    = 33.793 MILLION GALS
TOTAL H2 LOST WITH NO SYSTEM   =  8.549 MILLION LBS      TOTAL POWER EXPENDED    = 22.558 MILLION KW-HR
TOTAL H2 VENTED BY SYSTEM      =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED        =  9.41  MILLION LBS
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ORIGINAL PAGE IS
OF POOR QUALITY

- LIFE CYCLE COST ------SYSTEM 2 5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 3326.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 251025.5 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50954.8	$ 4805.6	$ 749682.4	$ 439294.7	$ -310387.7
2	$ 55830.3	$ 5093.9	$ 60924.3	$ 439294.7	$ 378370.4
3	$ 61180.2	$ 5399.6	$ 66579.8	$ 439294.7	$ 372714.9
4	$ 67051.1	$ 5723.5	$ 72774.7	$ 439294.7	$ 366520.0
5	$ 73494.2	$ 6067.0	$ 79561.2	$ 439294.7	$ 359733.5
6	$ 80566.0	$ 6431.0	$ 86997.0	$ 439294.7	$ 352297.7
7	$ 88328.2	$ 6816.8	$ 95145.1	$ 439294.7	$ 344149.6
8	$ 96849.0	$ 7225.8	$ 104074.9	$ 439294.7	$ 335219.8
9	$ 106203.2	$ 7659.4	$ 113862.6	$ 439294.7	$ 325432.1
10	$ 116473.0	$ 8119.0	$ 124591.9	$ 439294.7	$ 314702.8
11	$ 127748.7	$ 8606.1	$ 136354.7	$ 439294.7	$ 302939.9
12	$ 140129.6	$ 9122.5	$ 149252.1	$ 439294.7	$ 290042.6
13	$ 153725.0	$ 9669.8	$ 163394.8	$ 439294.7	$ 275899.8
14	$ 168654.9	$ 10250.0	$ 178904.9	$ 439294.7	$ 260389.8
15	$ 185051.3	$ 10865.0	$ 195916.3	$ 439294.7	$ 243378.4
16	$ 203059.1	$ 11516.9	$ 214576.0	$ 439294.7	$ 224718.7
17	$ 222837.9	$ 12207.9	$ 235045.8	$ 439294.7	$ 204248.9
18	$ 244562.9	$ 12940.4	$ 257503.3	$ 439294.7	$ 181791.4
19	$ 268426.9	$ 13716.8	$ 282143.7	$ 439294.7	$ 157151.0
20	$ 294641.8	$ 14539.8	$ 309181.6	$ 439294.7	$ 130113.1
	$ 2805768.3	$ 176776.8	$ 3676467.2	$ 8765893.8	$ 5109426.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 5.109 MILLION DOLLARS

-------------- IN 20 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 5.021 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .139 MILLION LBS
TOTAL NITROGEN EXPENDED = 8.969 MILLION LBS
TOTAL WATER EXPENDED = 33.793 MILLION GALS
TOTAL POWER EXPENDED = 22.558 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (1.00) $ 693922.00

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 3884.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 257590.3 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 693922.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50476.8	$ 4805.6	$ 749204.4	$ 450783.0	$ -298421.4
2	$ 55304.6	$ 5093.9	$ 60398.5	$ 450783.0	$ 390384.5
3	$ 60601.9	$ 5399.6	$ 66001.4	$ 450783.0	$ 384781.6
4	$ 66414.9	$ 5723.5	$ 72138.5	$ 450783.0	$ 378644.6
5	$ 72794.4	$ 6067.0	$ 78861.4	$ 450783.0	$ 371921.6
6	$ 79796.2	$ 6431.0	$ 86227.2	$ 450783.0	$ 364555.9
7	$ 87481.4	$ 6816.8	$ 94298.3	$ 450783.0	$ 356484.7
8	$ 95917.6	$ 7225.8	$ 103143.4	$ 450783.0	$ 347639.6
9	$ 105178.6	$ 7659.4	$ 112838.0	$ 450783.0	$ 337945.0
10	$ 115345.9	$ 8119.0	$ 123464.9	$ 450783.0	$ 327318.2
11	$ 126508.9	$ 8606.1	$ 135115.0	$ 450783.0	$ 315668.0
12	$ 138765.9	$ 9122.5	$ 147888.3	$ 450783.0	$ 302894.7
13	$ 152224.9	$ 9669.8	$ 161894.7	$ 450783.0	$ 288888.3
14	$ 167004.8	$ 10250.0	$ 177254.8	$ 450783.0	$ 273528.2
15	$ 183236.1	$ 10865.0	$ 194101.1	$ 450783.0	$ 256681.9
16	$ 201062.4	$ 11516.9	$ 212579.3	$ 450783.0	$ 238203.7
17	$ 220641.5	$ 12207.9	$ 232849.5	$ 450783.0	$ 217933.6
18	$ 242146.9	$ 12940.4	$ 255087.3	$ 450783.0	$ 195695.7
19	$ 265769.3	$ 13716.8	$ 279486.2	$ 450783.0	$ 171296.9
20	$ 291718.4	$ 14539.8	$ 306258.3	$ 450783.0	$ 144524.7
	$ 2778391.6	$ 176776.8	$ 3649090.4	$ 9015660.4	$ 5366569.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 20 YEARS = 5.367 MILLION DOLLARS

-------------- IN 20 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 5.152 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 8.549 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .278 MILLION LBS
TOTAL NITROGEN EXPENDED = 8.736 MILLION LBS

TOTAL WATER EXPENDED = 33.793 MILLION GALS
TOTAL POWER EXPENDED = 22.558 MILLION KW-HR

```
 - LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 YEAR LIFE

CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  470965.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                   -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.00)  $  693922.00

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH = 5374.0 GAL/LOADING
                                      DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  275119.8 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  693922.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 49893.2	$ 4805.6	$ 748620.8	$ 481459.7	$ -267161.'
2	$ 54662.6	$ 5093.9	$ 59756.5	$ 481459.7	$ 421703.2
3	$ 59895.7	$ 5399.6	$ 65295.2	$ 481459.7	$ 416164.5
4	$ 65638.1	$ 5723.5	$ 71361.6	$ 481459.7	$ 410098.1
5	$ 71939.9	$ 6067.0	$ 78006.9	$ 481459.7	$ 403452.8
6	$ 78856.2	$ 6431.0	$ 85287.2	$ 481459.7	$ 396172.5
7	$ 86447.5	$ 6816.8	$ 93264.3	$ 481459.7	$ 388195.4
8	$ 94780.3	$ 7225.8	$ 102006.1	$ 481459.7	$ 379453.6
9	$ 103927.5	$ 7659.4	$ 111586.9	$ 481459.7	$ 369872.8
10	$ 113969.7	$ 8119.0	$ 122088.7	$ 481459.7	$ 359371.0
11	$ 124995.1	$ 8606.1	$ 133601.2	$ 481459.7	$ 347858.5
12	$ 137100.7	$ 9122.5	$ 146223.2	$ 481459.7	$ 335236.6
13	$ 150393.2	$ 9669.8	$ 160063.0	$ 481459.7	$ 321396.7
14	$ 164989.9	$ 10250.0	$ 175239.9	$ 481459.7	$ 306219.8
15	$ 181019.8	$ 10865.0	$ 191884.8	$ 481459.7	$ 289574.9
16	$ 198624.5	$ 11516.9	$ 210141.4	$ 481459.7	$ 271318.4
17	$ 217959.8	$ 12207.9	$ 230167.7	$ 481459.7	$ 251292.0
18	$ 239197.0	$ 12940.4	$ 252137.4	$ 481459.7	$ 229322.3
19	$ 262524.4	$ 13716.8	$ 276241.2	$ 481459.7	$ 205218.5
20	$ 288149.0	$ 14539.8	$ 302688.8	$ 481459.7	$ 178770.9
	$ 2744964.2	$ 176776.8	$ 3615663.0	$ 9629194.7	$ 6013531.7

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 20 YEARS = 6.014 MILLION DOLLARS

-------------- IN 20 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  5.502 MILLION LBS      TOTAL WATER EXPENDED   = 33.793 MILLION GALS
TOTAL H2 LOST WITH NO SYSTEM  =  8.549 MILLION LBS      TOTAL POWER EXPENDED   = 22.558 MILLION KW-HR
TOTAL H2 VENTED BY SYSTEM     =   .696 MILLION LBS
TOTAL NITROGEN EXPENDED       =  8.451 MILLION LBS
```

- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % $ -DELTA

```
CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  178249.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                   -----------      WATER RATE= .0003 $/GAL
  TOTAL * ( .80)  $  320964.80

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH =     0.  GAL/LOADING
                                      DEWAR LOADING  =     0.  GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  80901.8 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 320964.80

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 347047.7	$ 141578.2	$ -205469.5
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
	$ 632151.2	$ 111855.0	$ 1064971.0	$ 2123672.9	$ 1058701.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.059 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM     =  1.214 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM      =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED        =  2.524 MILLION LBS
TOTAL WATER EXPENDED           =  8.624 MILLION GALS
TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % $ -DELTA

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 178249.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (.80) $ 320964.80

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 161.8 GAL/LOADING
DEWAR LOADING = 692.8 GAL/LOADING
TOTAL = 90956.0 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 5.8%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 320964.80

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20203.1	$ 4805.6	$ 345973.5	$ 159173.0	$ -186800.4
2	$ 22016.8	$ 5093.9	$ 27110.7	$ 159173.0	$ 132062.3
3	$ 23999.5	$ 5399.6	$ 29399.1	$ 159173.0	$ 129773.9
4	$ 26167.4	$ 5723.5	$ 31890.9	$ 159173.0	$ 127282.1
5	$ 28538.1	$ 6067.0	$ 34605.0	$ 159173.0	$ 124568.0
6	$ 31131.1	$ 6431.0	$ 37562.0	$ 159173.0	$ 121611.0
7	$ 33967.7	$ 6816.8	$ 40784.6	$ 159173.0	$ 118388.5
8	$ 37071.5	$ 7225.8	$ 44297.3	$ 159173.0	$ 114875.7
9	$ 40468.0	$ 7659.4	$ 48127.4	$ 159173.0	$ 111045.7
10	$ 44185.5	$ 8119.0	$ 52304.5	$ 159173.0	$ 106868.6
11	$ 48255.1	$ 8606.1	$ 56861.2	$ 159173.0	$ 102311.9
12	$ 52710.6	$ 9122.5	$ 61833.1	$ 159173.0	$ 97340.0
13	$ 57589.5	$ 9669.8	$ 67259.3	$ 159173.0	$ 91913.7
14	$ 62932.8	$ 10250.0	$ 73182.8	$ 159173.0	$ 85990.2
15	$ 68785.5	$ 10865.0	$ 79650.5	$ 159173.0	$ 79522.6
	$ 598022.0	$ 111855.0	$ 1030841.8	$ 2367595.6	$ 1356753.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.357 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 1.364 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .123 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.131 MILLION LBS
TOTAL WATER EXPENDED = 8.624 MILLION GALS
TOTAL POWER EXPENDED = 5.758 MILLION KW-HR

```
     - LIFE CYCLE COST ------SYSTEM 1 10% VENTING
   ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % $ -DELTA

 CAPITAL INVESTMENT COST              OPERATING COST
   EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
   DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
   FABRICATION     =$  123940.00        POWER RATE=  .024 $/KW-HR
   INSTALLATION    =$   51883.00        LN2 RATE  =  .041 $/LB
                      -----------       WATER RATE= .0003 $/GAL
   TOTAL * ( .80)  $  320964.80

 MAINTENANCE COST DATA                SAVINGS DATA
   LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
   LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
   MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =  297.6 GAL/LOADING
                                          DEWAR LOADING  = 1276.8 GAL/LOADING
 ESCALATION RATES,PERCENT/YEAR            TOTAL          =  99424.3 LB/YEAR
   OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
   MAINTEN. LABOR =  6.00
   MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
   POWER          = 10.00               PERCENT DOWN TIME              =  5.8%
   LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
   WATER          =  6.00               NO. OF DEWAR LOADINGS/YR    =  20.0
   LIQ. HYDROGEN  =  0.

 ------------------------ CASH FLOW --------------------------------
           TOTAL CAPITAL INVESTMENT COST = $  320964.80
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 19576.2	$ 4805.6	$ 345346.6	$ 173992.6	$ -171354.0
2	$ 21327.2	$ 5093.9	$ 26421.1	$ 173992.6	$ 147571.4
3	$ 23240.9	$ 5399.6	$ 28640.5	$ 173992.6	$ 145352.1
4	$ 25332.9	$ 5723.5	$ 31056.5	$ 173992.6	$ 142936.1
5	$ 27620.2	$ 6067.0	$ 33687.1	$ 173992.6	$ 140305.4
6	$ 30121.4	$ 6431.0	$ 36552.4	$ 173992.6	$ 137440.2
7	$ 32857.1	$ 6816.8	$ 39673.9	$ 173992.6	$ 134318.7
8	$ 35849.7	$ 7225.8	$ 43075.6	$ 173992.6	$ 130917.0
9	$ 39124.1	$ 7659.4	$ 46783.5	$ 173992.6	$ 127209.1
10	$ 42707.3	$ 8119.0	$ 50826.2	$ 173992.6	$ 123166.3
11	$ 46629.0	$ 8606.1	$ 55235.1	$ 173992.6	$ 118757.5
12	$ 50921.9	$ 9122.5	$ 60044.4	$ 173992.6	$ 113948.2
13	$ 55622.0	$ 9669.8	$ 65291.8	$ 173992.6	$ 108700.8
14	$ 60768.5	$ 10250.0	$ 71018.5	$ 173992.6	$ 102974.1
15	$ 66404.7	$ 10865.0	$ 77269.7	$ 173992.6	$ 96722.9
	$ 578103.0	$ 111855.0	$ 1010922.8	$ 2609888.5	$ 1598965.7

```
      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 1.599 MILLION DOLLARS

      -------------- IN 15 YEARS ------------------
      TOTAL H2 SAVED WITH SYSTEM    =  1.491 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
      TOTAL NITROGEN EXPENDED       =  1.902 MILLION LBS
      TOTAL WATER EXPENDED          =  8.624 MILLION GALS
      TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

```
     - LIFE CYCLE COST ------SYSTEM 1 25% VENTING
  ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % $ -DELTA

CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  178249.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                    -----------     WATER RATE= .0003 $/GAL
  TOTAL * ( .80)  $  320964.80

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH =  654.8 GAL/LOADING
                                      DEWAR LOADING  = 2769.6 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  121189.2 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR       =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  320964.80

YEAR OPERATING  MAINTENANCE  TOTAL COST  GROSS SAVINGS  NET SAVINGS
       COST         COST

  1 $  18758.3  $    4805.6  $ 344528.7  $   212081.1   $ -132447.6
  2 $  20427.5  $    5093.9  $  25521.5  $   212081.1   $  186559.6
  3 $  22251.3  $    5399.6  $  27650.9  $   212081.1   $  184430.2
  4 $  24244.3  $    5723.5  $  29967.9  $   212081.1   $  182113.2
  5 $  26422.7  $    6067.0  $  32489.7  $   212081.1   $  179591.4
  6 $  28804.2  $    6431.0  $  35235.2  $   212081.1   $  176845.9
  7 $  31408.2  $    6816.8  $  38225.0  $   212081.1   $  173856.1
  8 $  34256.0  $    7225.8  $  41481.8  $   212081.1   $  170599.3
  9 $  37370.9  $    7659.4  $  45030.3  $   212081.1   $  167050.8
 10 $  40778.8  $    8119.0  $  48897.7  $   212081.1   $  163183.4
 11 $  44507.7  $    8606.1  $  53113.8  $   212081.1   $  158967.4
 12 $  48588.5  $    9122.5  $  57710.9  $   212081.1   $  154370.2
 13 $  53055.2  $    9669.8  $  62725.0  $   212081.1   $  149356.1
 14 $  57945.0  $   10250.0  $  68195.0  $   212081.1   $  143886.1
 15 $  63298.9  $   10865.0  $  74163.9  $   212081.1   $  137917.2
      ---------    ---------   ----------   ----------     ----------
   $  552117.5 $  111855.0 $   984937.3 $  3181216.6   $  2196279.3

      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 2.196 MILLION DOLLARS

      -------------- IN 15 YEARS -------------------
      TOTAL H2 SAVED WITH SYSTEM    =  1.818 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =   .615 MILLION LBS
      TOTAL NITROGEN EXPENDED       =  1.603 MILLION LBS
      TOTAL WATER EXPENDED          =  8.624 MILLION GALS
      TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ -DELT

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  275821.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE   =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * ( .80)  $  399022.40

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =  747.0 GAL/LOADING
                                         DEWAR LOADING  = 2988.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  128965.7 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 399022.40

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32533.4	$ 4805.6	$ 436361.4	$ 225690.0	$ -210671.4
2	$ 35575.8	$ 5093.9	$ 40669.7	$ 225690.0	$ 185020.3
3	$ 38909.8	$ 5399.6	$ 44309.3	$ 225690.0	$ 181380.7
4	$ 42563.7	$ 5723.5	$ 48287.3	$ 225690.0	$ 177402.8
5	$ 46568.9	$ 6067.0	$ 52635.8	$ 225690.0	$ 173054.2
6	$ 50959.4	$ 6431.0	$ 57390.4	$ 225690.0	$ 168299.6
7	$ 55773.1	$ 6816.8	$ 62589.9	$ 225690.0	$ 163100.1
8	$ 61051.2	$ 7225.8	$ 68277.0	$ 225690.0	$ 157413.0
9	$ 66839.1	$ 7659.4	$ 74498.5	$ 225690.0	$ 151191.6
10	$ 73186.8	$ 8119.0	$ 81305.7	$ 225690.0	$ 144384.3
11	$ 80149.1	$ 8606.1	$ 88755.2	$ 225690.0	$ 136934.9
12	$ 87786.2	$ 9122.5	$ 96908.7	$ 225690.0	$ 128781.4
13	$ 96164.4	$ 9669.8	$ 105834.2	$ 225690.0	$ 119855.8
14	$ 105356.4	$ 10250.0	$ 115606.4	$ 225690.0	$ 110083.7
15	$ 115442.1	$ 10865.0	$ 126307.1	$ 225690.0	$ 99383.0
	$ 988859.2	$ 111855.0	$ 1499736.6	$ 3385350.6	$ 1885614.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.886 MILLION DOLLARS

```
-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.934 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  4.471 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ -DELT

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 275821.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00

TOTAL * (.80) $ 399022.40

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

ESCALATION RATES,PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 1095.4 GAL/LOADING
  - DEWAR LOADING = 4484.8 GAL/LOADING
  - TOTAL = 150674.1 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 399022.40

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30338.3	$ 4805.6	$ 434166.3	$ 263679.8	$ -170486.5
2	$ 33161.2	$ 5093.9	$ 38255.1	$ 263679.8	$ 225424.6
3	$ 36253.7	$ 5399.6	$ 41653.3	$ 263679.8	$ 222026.5
4	$ 39642.0	$ 5723.5	$ 45365.6	$ 263679.8	$ 218314.2
5	$ 43355.0	$ 6067.0	$ 49422.0	$ 263679.8	$ 214257.8
6	$ 47424.2	$ 6431.0	$ 53855.2	$ 263679.8	$ 209824.6
7	$ 51884.3	$ 6816.8	$ 58701.1	$ 263679.8	$ 204978.6
8	$ 56773.5	$ 7225.8	$ 63999.4	$ 263679.8	$ 199680.4
9	$ 62133.7	$ 7659.4	$ 69793.1	$ 263679.8	$ 193886.7
10	$ 68010.8	$ 8119.0	$ 76129.8	$ 263679.8	$ 187550.0
11	$ 74455.5	$ 8606.1	$ 83061.6	$ 263679.8	$ 180618.1
12	$ 81523.3	$ 9122.5	$ 90645.8	$ 263679.8	$ 173034.0
13	$ 89275.2	$ 9669.8	$ 98945.0	$ 263679.8	$ 164734.7
14	$ 97778.3	$ 10250.0	$ 108028.3	$ 263679.8	$ 155651.5
15	$ 107106.2	$ 10865.0	$ 117971.2	$ 263679.8	$ 145708.6
	$ 919115.2	$ 111855.0	$ 1429992.6	$ 3955196.3	$ 2525203.8

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.525 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

- TOTAL H2 SAVED WITH SYSTEM = 2.260 MILLION LBS
- TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
- TOTAL H2 VENTED BY SYSTEM = .246 MILLION LBS
- TOTAL NITROGEN EXPENDED = 3.668 MILLION LBS
- TOTAL WATER EXPENDED = 14.062 MILLION GALS
- TOTAL POWER EXPENDED = 9.400 MILLION KW-HR

```
     - LIFE CYCLE COST ------SYSTEM 1 10% VENTING
  TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ -DELT

CAPITAL INVESTMENT COST           OPERATING COST
  EQUIP AND MATL= $  275821.00      LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00      LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00      POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00      LN2 RATE  =  .041 $/LB
                   -----------      WATER RATE= .0003 $/GAL
  TOTAL * ( .80)  $  399022.40

MAINTENANCE COST DATA             SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK          HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR              NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR          SHUTTLE LAUNCH = 1382.0 GAL/LOADING
                                      DEWAR LOADING  = 5704.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR         TOTAL          =  168389.6 LB/YEAR
  OPERATING LABOR=  6.00            LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00          OPERATIONAL PARAMETERS
  POWER          = 10.00            PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00            NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00            NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
        TOTAL CAPITAL INVESTMENT COST = $  399022.40

YEAR OPERATING  MAINTENANCE  TOTAL COST  GROSS SAVINGS  NET SAVINGS
       COST         COST

  1 $   28861.9  $    4805.6  $ 432689.9  $   294681.8   $ -138008.1
  2 $   31537.1  $    5093.9  $  36631.1  $   294681.8   $  258050.7
  3 $   34467.3  $    5399.6  $  39866.8  $   294681.8   $  254814.9
  4 $   37677.0  $    5723.5  $  43400.5  $   294681.8   $  251281.3
  5 $   41193.4  $    6067.0  $  47260.4  $   294681.8   $  247421.4
  6 $   45046.4  $    6431.0  $  51477.4  $   294681.8   $  243204.4
  7 $   49268.8  $    6816.8  $  56085.6  $   294681.8   $  238596.1
  8 $   53896.4  $    7225.8  $  61122.3  $   294681.8   $  233559.5
  9 $   58968.9  $    7659.4  $  66628.3  $   294681.8   $  228053.5
 10 $   64529.6  $    8119.0  $  72648.5  $   294681.8   $  222033.2
 11 $   70626.1  $    8606.1  $  79232.2  $   294681.8   $  215449.5
 12 $   77311.0  $    9122.5  $  86433.4  $   294681.8   $  208248.3
 13 $   84641.6  $    9669.8  $  94311.5  $   294681.8   $  200370.3
 14 $   92681.3  $   10250.0  $ 102931.3  $   294681.8   $  191750.4
 15 $  101499.5  $   10865.0  $ 112364.5  $   294681.8   $  182317.2
      ---------   ---------   ----------   ----------    ----------
   $  872206.5 $  111855.0 $  1383083.9 $  4420226.5    $ 3037142.7

      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 3.037 MILLION DOLLARS

      -------------- IN 15 YEARS ------------------
      TOTAL H2 SAVED WITH SYSTEM    =  2.526 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM     =   .492 MILLION LBS
      TOTAL NITROGEN EXPENDED       =  3.127 MILLION LBS
      TOTAL WATER EXPENDED          = 14.082 MILLION GALS
      TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 46 HRS 20 % $ -DELT

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (.80) $ 399022.40

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2122.0 GAL/LOADING
DEWAR LOADING = 8848.0 GAL/LOADING
TOTAL = 214084.1 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

---------------------- CASH FLOW ----------------------
TOTAL CAPITAL INVESTMENT COST = $ 399022.40

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 26656.8	$ 4305.6	$ 430484.8	$ 374647.1	$ -55837.7
2	$ 29111.6	$ 5093.9	$ 34205.5	$ 374647.1	$ 340441.6
3	$ 31799.1	$ 5399.6	$ 37198.7	$ 374647.1	$ 337448.4
4	$ 34742.0	$ 5723.5	$ 40465.6	$ 374647.1	$ 334181.6
5	$ 37965.0	$ 6067.0	$ 44031.9	$ 374647.1	$ 330615.2
6	$ 41495.2	$ 6431.0	$ 47926.1	$ 374647.1	$ 326721.0
7	$ 45362.4	$ 6816.8	$ 52179.2	$ 374647.1	$ 322467.9
8	$ 49599.4	$ 7225.8	$ 56825.2	$ 374647.1	$ 317821.9
9	$ 54242.1	$ 7659.4	$ 61901.5	$ 374647.1	$ 312745.6
10	$ 59330.1	$ 8119.0	$ 67449.1	$ 374647.1	$ 307198.0
11	$ 64906.8	$ 8606.1	$ 73512.9	$ 374647.1	$ 301134.2
12	$ 71019.7	$ 9122.5	$ 80142.1	$ 374647.1	$ 294505.0
13	$ 77721.2	$ 9669.8	$ 87391.0	$ 374647.1	$ 287256.1
14	$ 85068.9	$ 10250.0	$ 95318.9	$ 374647.1	$ 279328.3
15	$ 93125.8	$ 10865.0	$ 103990.8	$ 374647.1	$ 270656.3
	$ 802146.1	$ 111855.0	$ 1313023.5	$ 5619706.7	$ 4306683.2

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.307 MILLION DOLLARS

-------------- IN 15 YEARS --------------
TOTAL H2 SAVED WITH SYSTEM = 3.211 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 1.230 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.321 MILLION LBS
TOTAL WATER EXPENDED = 14.082 MILLION GALS
TOTAL POWER EXPENDED = 9.400 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ -DELT

CAPITAL INVESTMENT COST	
EQUIP AND MATL=	$ 470965.00
DETAILED DESIGN=	$ 47134.00
FABRICATION =	$ 123940.00
INSTALLATION =	$ 51883.00
TOTAL * (.80)	$ 555137.60

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2696.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 243613.7 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 555137.60

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 51862.7	$ 4805.6	$ 611805.9	$ 426324.0	$ -185481.9
2	$ 56829.1	$ 5093.9	$ 61923.0	$ 426324.0	$ 364401.0
3	$ 62278.8	$ 5399.6	$ 67678.4	$ 426324.0	$ 358645.6
4	$ 68259.5	$ 5723.5	$ 73983.1	$ 426324.0	$ 352340.9
5	$ 74823.5	$ 6067.0	$ 80890.5	$ 426324.0	$ 345433.5
6	$ 82028.2	$ 6431.0	$ 88459.2	$ 426324.0	$ 337864.8
7	$ 89936.7	$ 6816.8	$ 96753.5	$ 426324.0	$ 329570.5
8	$ 98618.3	$ 7225.8	$ 105844.2	$ 426324.0	$ 320479.8
9	$ 108149.4	$ 7659.4	$ 115808.8	$ 426324.0	$ 310515.2
10	$ 118613.8	$ 8119.0	$ 126732.7	$ 426324.0	$ 299591.3
11	$ 130103.6	$ 8606.1	$ 138709.7	$ 426324.0	$ 287614.3
12	$ 142720.0	$ 9122.5	$ 151842.5	$ 426324.0	$ 274481.5
13	$ 156574.5	$ 9669.8	$ 166244.3	$ 426324.0	$ 260079.7
14	$ 171789.3	$ 10250.0	$ 182039.3	$ 426324.0	$ 244284.7
15	$ 188499.1	$ 10865.0	$ 199364.1	$ 426324.0	$ 226959.9
	$ 1601086.5	$ 111855.0	$ 2268079.1	$ 6394860.0	$ 4126780.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.127 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.654 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
TOTAL NITROGEN EXPENDED = 7.059 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 2 5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ -DELT

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  470965.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE   =  .041 $/LB
                   -----------         WATER RATE= .0003 $/GAL
  TOTAL * ( .80)  $  555137.60

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH = 3326.0 GAL/LOADING
                                        DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          =  251025.5 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 555137.60

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50954.8	$ 4805.6	$ 610898.0	$ 439294.7	$ -171603.3
2	$ 55830.3	$ 5093.9	$ 60924.3	$ 439294.7	$ 378370.4
3	$ 61180.2	$ 5399.6	$ 66579.8	$ 439294.7	$ 372714.9
4	$ 67051.1	$ 5723.5	$ 72774.7	$ 439294.7	$ 366520.0
5	$ 73494.2	$ 6067.0	$ 79561.2	$ 439294.7	$ 359733.5
6	$ 80566.0	$ 6431.0	$ 86997.0	$ 439294.7	$ 352297.7
7	$ 88328.2	$ 6816.8	$ 95145.1	$ 439294.7	$ 344149.6
8	$ 96849.0	$ 7225.9	$ 104074.9	$ 439294.7	$ 335219.8
9	$ 106203.2	$ 7659.4	$ 113862.6	$ 439294.7	$ 325432.1
10	$ 116473.0	$ 8119.0	$ 124591.9	$ 439294.7	$ 314702.8
11	$ 127748.7	$ 8606.1	$ 136354.7	$ 439294.7	$ 302939.9
12	$ 140129.6	$ 9122.5	$ 149252.1	$ 439294.7	$ 290042.6
13	$ 153725.0	$ 9669.8	$ 163394.8	$ 439294.7	$ 275899.8
14	$ 168654.9	$ 10250.0	$ 178904.9	$ 439294.7	$ 260389.8
15	$ 185051.3	$ 10865.0	$ 195916.3	$ 439294.7	$ 243378.4
	$ 1572239.7	$ 111855.0	$ 2239232.3	$ 6589420.4	$ 4350188.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.350 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.765 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .104 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.727 MILLION LBS
TOTAL WATER EXPENDED          = 25.344 MILLION GALS
TOTAL POWER EXPENDED          = 16.919 MILLION KW-HR
```

```
     - LIFE CYCLE COST ------SYSTEM 2 10% VENTING
 FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ -DELT

CAPITAL INVESTMENT COST               OPERATING COST
  EQUIP AND MATL= $  470965.00          LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00          LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00          POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00          LN2 RATE  =  .041 $/LB
                    -----------         WATER RATE= .0003 $/GAL
  TOTAL * ( .80)  $  555137.60

MAINTENANCE COST DATA                 SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK              HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                  NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR              SHUTTLE LAUNCH = 3884.0 GAL/LOADING
                                          DEWAR LOADING  =10784.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR             TOTAL          =  257590.3 LB/YEAR
  OPERATING LABOR=  6.00                LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00              OPERATIONAL PARAMETERS
  POWER          = 10.00                PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00                NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00                NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  555137.60
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50476.8	$ 4805.6	$ 610420.0	$ 450783.0	$ -159637.0
2	$ 55304.6	$ 5093.9	$ 60398.5	$ 450783.0	$ 390384.5
3	$ 60601.9	$ 5399.6	$ 66001.4	$ 450783.0	$ 384781.6
4	$ 66414.9	$ 5723.5	$ 72138.5	$ 450783.0	$ 378644.6
5	$ 72794.4	$ 6067.0	$ 78861.4	$ 450783.0	$ 371921.6
6	$ 79796.2	$ 6431.0	$ 86227.2	$ 450783.0	$ 364555.9
7	$ 87481.4	$ 6816.8	$ 94298.3	$ 450783.0	$ 356484.7
8	$ 95917.6	$ 7225.8	$ 103143.4	$ 450783.0	$ 347639.6
9	$ 105178.6	$ 7659.4	$ 112838.0	$ 450783.0	$ 337945.0
10	$ 115345.9	$ 8119.0	$ 123464.9	$ 450783.0	$ 327318.2
11	$ 126508.9	$ 8606.1	$ 135115.0	$ 450783.0	$ 315668.0
12	$ 138765.9	$ 9122.5	$ 147888.3	$ 450783.0	$ 302894.7
13	$ 152224.9	$ 9669.8	$ 161894.7	$ 450783.0	$ 288888.3
14	$ 167004.8	$ 10250.0	$ 177254.8	$ 450783.0	$ 273528.2
15	$ 183236.1	$ 10865.0	$ 194101.1	$ 450783.0	$ 256681.9
	$ 1557052.9	$ 111855.0	$ 2224045.5	$ 6761745.3	$ 4537699.[illegible]

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      PAY BACK OCCURS DURING YEAR  3
      NET SAVINGS OVER 15 YEARS = 4.538 MILLION DOLLARS

      -------------- IN 15 YEARS ------------------
      TOTAL H2 SAVED WITH SYSTEM     =  3.864 MILLION LBS
      TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
      TOTAL H2 VENTED BY SYSTEM      =   .209 MILLION LBS
      TOTAL NITROGEN EXPENDED        =  6.552 MILLION LBS
      TOTAL WATER EXPENDED           = 25.344 MILLION GALS
      TOTAL POWER EXPENDED           = 16.919 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ -DELT

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00
TOTAL * (.80) $ 555137.60

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 5374.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 275119.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 555137.60

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 49893.2	$ 4805.6	$ 609836.4	$ 481459.7	$ -128376.7
2	$ 54662.6	$ 5093.9	$ 59756.5	$ 481459.7	$ 421703.2
3	$ 59895.7	$ 5399.6	$ 65295.2	$ 481459.7	$ 416164.5
4	$ 65638.1	$ 5723.5	$ 71361.6	$ 481459.7	$ 410098.1
5	$ 71939.9	$ 6067.0	$ 78006.9	$ 481459.7	$ 403452.8
6	$ 78356.2	$ 6431.0	$ 85287.2	$ 481459.7	$ 396172.5
7	$ 86447.5	$ 6816.8	$ 93264.3	$ 481459.7	$ 388195.4
8	$ 94780.3	$ 7225.8	$ 102006.1	$ 481459.7	$ 379453.6
9	$ 103927.5	$ 7659.4	$ 111586.9	$ 481459.7	$ 369872.8
10	$ 113969.7	$ 8119.0	$ 122088.7	$ 481459.7	$ 359371.0
11	$ 124995.1	$ 8606.1	$ 133601.2	$ 481459.7	$ 347858.5
12	$ 137100.7	$ 9122.5	$ 146223.2	$ 481459.7	$ 335236.6
13	$ 150393.2	$ 9669.8	$ 160063.0	$ 481459.7	$ 321396.7
14	$ 164989.9	$ 10250.0	$ 175239.9	$ 481459.7	$ 306219.8
15	$ 181019.8	$ 10865.0	$ 191884.8	$ 481459.7	$ 289574.9
	$ 1538509.5	$ 111855.0	$ 2205502.1	$ 7221896.0	$ 5016393.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 5.016 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 4.127 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .522 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.338 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 1 NO VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % $ DELTA

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 178249.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.20) $ 481447.20

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 0. GAL/LOADING
  - DEWAR LOADING = 0. GAL/LOADING
  - TOTAL = 80901.8 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 5.8%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW ------------------------

TOTAL CAPITAL INVESTMENT COST = $ 481447.20

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 21277.3	$ 4805.6	$ 507530.1	$ 141578.2	$ -365951.9
2	$ 23198.4	$ 5093.9	$ 28292.3	$ 141578.2	$ 113285.9
3	$ 25299.3	$ 5399.6	$ 30698.8	$ 141578.2	$ 110879.4
4	$ 27597.1	$ 5723.5	$ 33320.6	$ 141578.2	$ 108257.6
5	$ 30110.8	$ 6067.0	$ 36177.7	$ 141578.2	$ 105400.5
6	$ 32861.0	$ 6431.0	$ 39292.0	$ 141578.2	$ 102286.2
7	$ 35870.7	$ 6816.8	$ 42687.5	$ 141578.2	$ 98890.7
8	$ 39164.7	$ 7225.8	$ 46390.6	$ 141578.2	$ 95187.6
9	$ 42770.6	$ 7659.4	$ 50430.0	$ 141578.2	$ 91148.2
10	$ 46718.4	$ 8119.0	$ 54837.3	$ 141578.2	$ 86740.9
11	$ 51041.2	$ 8606.1	$ 59647.3	$ 141578.2	$ 81930.9
12	$ 55775.4	$ 9122.5	$ 64897.8	$ 141578.2	$ 76680.4
13	$ 60960.7	$ 9669.8	$ 70630.6	$ 141578.2	$ 70947.6
14	$ 66641.1	$ 10250.0	$ 76891.1	$ 141578.2	$ 64687.0
15	$ 72864.6	$ 10865.0	$ 83729.6	$ 141578.2	$ 57848.6
	$ 632151.2	$ 111855.0	$ 1225453.4	$ 2123672.9	$ 898219.5

PAY BACK OCCURS DURING YEAR 5
NET SAVINGS OVER 15 YEARS = .898 MILLION DOLLARS

------------- IN 15 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM	= 1.214 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	= 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	= 0. MILLION LBS
TOTAL NITROGEN EXPENDED	= 2.524 MILLION LBS
TOTAL WATER EXPENDED	= 8.624 MILLION GALS
TOTAL POWER EXPENDED	= 5.758 MILLION KW-HR

```
 - LIFE CYCLE COST ------SYSTEM 1  5% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % ↓ DELTA

CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  178249.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                   -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.20)  $  481447.20

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  161.8 GAL/LOADING
                                       DEWAR LOADING  =  692.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  90956.0 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME            =  5.8%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW -------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  481447.20
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 20203.1	$ 4805.6	$ 506455.9	$ 159173.0	$ -347282.8
2	$ 22016.8	$ 5093.9	$ 27110.7	$ 159173.0	$ 132062.3
3	$ 23999.5	$ 5399.6	$ 29399.1	$ 159173.0	$ 129773.9
4	$ 26167.4	$ 5723.5	$ 31890.9	$ 159173.0	$ 127282.1
5	$ 28538.1	$ 6067.0	$ 34605.0	$ 159173.0	$ 124568.0
6	$ 31131.1	$ 6431.0	$ 37562.0	$ 159173.0	$ 121611.0
7	$ 33967.7	$ 6816.8	$ 40784.6	$ 159173.0	$ 118388.5
8	$ 37071.5	$ 7225.8	$ 44297.3	$ 159173.0	$ 114875.7
9	$ 40468.0	$ 7659.4	$ 48127.4	$ 159173.0	$ 111045.7
10	$ 44185.5	$ 8119.0	$ 52304.5	$ 159173.0	$ 106868.6
11	$ 48255.1	$ 8606.1	$ 56861.2	$ 159173.0	$ 102311.9
12	$ 52710.6	$ 9122.5	$ 61833.1	$ 159173.0	$ 97340.0
13	$ 57589.5	$ 9669.8	$ 67259.3	$ 159173.0	$ 91913.7
14	$ 62932.8	$ 10250.0	$ 73182.8	$ 159173.0	$ 85990.2
15	$ 68785.5	$ 10865.0	$ 79650.5	$ 159173.0	$ 79522.6
	$ 598022.0	$ 111855.0	$ 1191324.2	$ 2387595.6	$ 1196271.4

```
     PAY BACK OCCURS DURING YEAR  4
     NET SAVINGS OVER 15 YEARS = 1.196 MILLION DOLLARS

     -------------- IN 15 YEARS ------------------
     TOTAL H2 SAVED WITH SYSTEM     =  1.364 MILLION LBS
     TOTAL H2 LOST WITH NO SYSTEM   =  6.412 MILLION LBS
     TOTAL H2 VENTED BY SYSTEM      =   .123 MILLION LBS
     TOTAL NITROGEN EXPENDED        =  2.131 MILLION LBS
     TOTAL WATER EXPENDED           =  8.624 MILLION GALS
     TOTAL POWER EXPENDED           =  5.758 MILLION KW-HR
```

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 - LIFE CYCLE COST ------SYSTEM 1 10% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % ~ DELTA

CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  178249.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE   =  .041 $/LB
                   -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.20)  $  481447.20

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR            SHUTTLE LAUNCH =  297.6 GAL/LOADING
                                        DEWAR LOADING  = 1276.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR           TOTAL          =   99424.3 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME              =  5.8%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.

------------------------- CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  481447.20

YEAR OPERATING   MAINTENANCE   TOTAL COST   GROSS SAVINGS   NET SAVINGS
       COST          COST

  1 $  19576.2  $    4805.6   $ 505829.0  $    173992.6    $ -331836.4
  2 $  21327.2  $    5093.9   $  26421.1  $    173992.6    $  147571.4
  3 $  23240.9  $    5399.6   $  28640.5  $    173992.6    $  145352.1
  4 $  25332.9  $    5723.5   $  31056.5  $    173992.6    $  142936.1
  5 $  27620.2  $    6067.0   $  33687.1  $    173992.6    $  140305.4
  6 $  30121.4  $    6431.0   $  36552.4  $    173992.6    $  137440.2
  7 $  32857.1  $    6816.8   $  39673.9  $    173992.6    $  134318.7
  8 $  35849.7  $    7225.8   $  43075.6  $    173992.6    $  130917.0
  9 $  39124.1  $    7659.4   $  46783.5  $    173992.6    $  127209.1
 10 $  42707.3  $    8119.0   $  50826.2  $    173992.6    $  123166.3
 11 $  46629.0  $    8606.1   $  55235.1  $    173992.6    $  118757.5
 12 $  50921.9  $    9122.5   $  60044.4  $    173992.6    $  113948.2
 13 $  55622.0  $    9669.8   $  65291.8  $    173992.6    $  108700.8
 14 $  60768.5  $   10250.0   $  71018.5  $    173992.6    $  102974.1
 15 $  66404.7  $   10865.0   $  77269.7  $    173992.6    $   96722.9
     ---------    ---------    ----------   ----------       ----------
   $  578103.0 $   111855.0 $  1171405.2 $  2609888.5     $  1438483.3

       PAY BACK OCCURS DURING YEAR  4
       NET SAVINGS OVER 15 YEARS = 1.438 MILLION DOLLARS

       -------------- IN 15 YEARS ------------------
       TOTAL H2 SAVED WITH SYSTEM    =  1.491 MILLION LBS
       TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
       TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
       TOTAL NITROGEN EXPENDED       =  1.902 MILLION LBS
       TOTAL WATER EXPENDED          =  8.624 MILLION GALS
       TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

ORIGINAL PAGE IS
OF POOR QUALITY

- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
ONE COMPRESSOR, 20 LAUNCHES, 48 HRS 20 % ⌄ DELTA

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CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  178249.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.20)  $  481447.20

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =  654.8 GAL/LOADING
                                         DEWAR LOADING  = 2769.6 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  121189.2 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME             =  5.8%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 481447.20

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 18758.3	$ 4805.6	$ 505011.1	$ 212081.1	$ -292930.0
2	$ 20427.5	$ 5093.9	$ 25521.5	$ 212081.1	$ 186559.6
3	$ 22251.3	$ 5399.6	$ 27650.9	$ 212081.1	$ 184430.2
4	$ 24244.3	$ 5723.5	$ 29967.9	$ 212081.1	$ 182113.2
5	$ 26422.7	$ 6067.0	$ 32489.7	$ 212081.1	$ 179591.4
6	$ 28804.2	$ 6431.0	$ 35235.2	$ 212081.1	$ 176845.9
7	$ 31408.2	$ 6816.8	$ 38225.0	$ 212081.1	$ 173856.1
8	$ 34256.0	$ 7225.8	$ 41481.8	$ 212081.1	$ 170599.3
9	$ 37370.9	$ 7659.4	$ 45030.3	$ 212081.1	$ 167050.8
10	$ 40778.8	$ 8119.0	$ 48897.7	$ 212081.1	$ 163183.4
11	$ 44507.7	$ 8606.1	$ 53113.8	$ 212081.1	$ 158967.4
12	$ 48588.5	$ 9122.5	$ 57710.9	$ 212081.1	$ 154370.2
13	$ 53055.2	$ 9669.8	$ 62725.0	$ 212081.1	$ 149356.1
14	$ 57945.0	$ 10250.0	$ 68195.0	$ 212081.1	$ 143886.1
15	$ 63298.9	$ 10865.0	$ 74163.9	$ 212081.1	$ 137917.2
	$ 552117.5	$ 111855.0	$ 1145419.7	$ 3161216.6	$ 2035796.9

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.036 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.818 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .615 MILLION LBS
TOTAL NITROGEN EXPENDED       =  1.603 MILLION LBS
TOTAL WATER EXPENDED          =  8.624 MILLION GALS
TOTAL POWER EXPENDED          =  5.758 MILLION KW-HR
```

```
    - LIFE CYCLE COST ------SYSTEM 1  NO VENTING
  TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % , DELTA

CAPITAL INVESTMENT COST            OPERATING COST
  EQUIP AND MATL= $  275821.00       LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00       LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00       POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00       LN2 RATE  =  .041 $/LB
                   -----------       WATER RATE= .0003 $/GAL
  TOTAL * (1.20)  $  598533.60

MAINTENANCE COST DATA              SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK           HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH =  747.0 GAL/LOADING
                                       DEWAR LOADING  = 2988.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  128965.7 LB/YEAR
  OPERATING LABOR=  6.00             LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00           OPERATIONAL PARAMETERS
  POWER          = 10.00             PERCENT DOWN TIME               =  1.0%
  LIQ NITROGEN   = 10.00             NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00             NO. OF DEWAR LOADINGS/YR    =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  598533.60
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 32533.4	$ 4805.6	$ 635872.6	$ 225690.0	$ -410182.6
2	$ 35575.8	$ 5093.9	$ 40669.7	$ 225690.0	$ 185020.3
3	$ 38909.8	$ 5399.6	$ 44309.3	$ 225690.0	$ 181380.7
4	$ 42563.7	$ 5723.5	$ 48287.3	$ 225690.0	$ 177402.8
5	$ 46568.9	$ 6067.0	$ 52635.8	$ 225690.0	$ 173054.2
6	$ 50959.4	$ 6431.0	$ 57390.4	$ 225690.0	$ 168299.6
7	$ 55773.1	$ 6816.8	$ 62589.9	$ 225690.0	$ 163100.1
8	$ 61051.2	$ 7225.8	$ 68277.0	$ 225690.0	$ 157413.0
9	$ 66839.1	$ 7659.4	$ 74498.5	$ 225690.0	$ 151191.6
10	$ 73186.8	$ 8119.0	$ 81305.7	$ 225690.0	$ 144384.3
11	$ 80149.1	$ 8606.1	$ 88755.2	$ 225690.0	$ 136934.9
12	$ 87786.2	$ 9122.5	$ 96908.7	$ 225690.0	$ 128781.4
13	$ 96164.4	$ 9669.8	$ 105834.2	$ 225690.0	$ 119855.8
14	$ 105356.4	$ 10250.0	$ 115606.4	$ 225690.0	$ 110083.7
15	$ 115442.1	$ 10865.0	$ 126307.1	$ 225690.0	$ 99383.0
	$ 988859.2	$ 111855.0	$ 1699247.8	$ 3385350.6	$ 1686102.8

```
PAY BACK OCCURS DURING YEAR  4
NET SAVINGS OVER 15 YEARS = 1.686 MILLION DOLLARS

------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  1.934 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =  0.    MILLION LBS
TOTAL NITROGEN EXPENDED       =  4.471 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 1 5% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % ⌄ DELTA

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  275821.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW*HR
  INSTALLATION   =$   51883.00         LN2 RATE  =  .041 $/LB
                   -----------         WATER RATE= .0003 $/GAL
  TOTAL * (1.20)  $  598533.60

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 1095.4 GAL/LOADING
                                         DEWAR LOADING  = 4484.8 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  150674.1 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR      =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 598533.60

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 30338.3	$ 4805.6	$ 633677.5	$ 263679.8	$ -369997.7
2	$ 33161.2	$ 5093.9	$ 38255.1	$ 263679.8	$ 225424.6
3	$ 36253.7	$ 5399.6	$ 41653.3	$ 263679.8	$ 222026.5
4	$ 39642.0	$ 5723.5	$ 45365.6	$ 263679.8	$ 218314.2
5	$ 43355.0	$ 6067.0	$ 49422.0	$ 263679.8	$ 214257.8
6	$ 47424.2	$ 6431.0	$ 53855.2	$ 263679.8	$ 209824.6
7	$ 51884.3	$ 6816.8	$ 58701.1	$ 263679.8	$ 204978.6
8	$ 56773.5	$ 7225.8	$ 63999.4	$ 263679.8	$ 199680.4
9	$ 62133.7	$ 7659.4	$ 69793.1	$ 263679.8	$ 193886.7
10	$ 68010.8	$ 8119.0	$ 76129.8	$ 263679.8	$ 187550.0
11	$ 74455.5	$ 8606.1	$ 83061.6	$ 263679.8	$ 180618.1
12	$ 81523.3	$ 9122.5	$ 90645.8	$ 263679.8	$ 173034.0
13	$ 89275.2	$ 9669.8	$ 98945.0	$ 263679.8	$ 164734.7
14	$ 97778.3	$ 10250.0	$ 108028.3	$ 263679.8	$ 155651.5
15	$ 107106.2	$ 10865.0	$ 117971.2	$ 263679.8	$ 145708.6
	$ 919115.2	$ 111855.0	$ 1629503.8	$ 3955196.3	$ 2325692.6

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.326 MILLION DOLLARS

```
-------------- IN 15 YEARS -----------------
TOTAL H2 SAVED WITH SYSTEM    =  2.260 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .246 MILLION LBS
TOTAL NITROGEN EXPENDED       =  3.668 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 1 10% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % ↓ DELTA

```
CAPITAL INVESTMENT COST              OPERATING COST
  EQUIP AND MATL= $  275821.00         LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00         LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00         POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00         LN2 RATE   =  .041 $/LB
                    -----------        WATER RATE= .0003 $/GAL
  TOTAL * (1.20)  $  598533.60

MAINTENANCE COST DATA                SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH = 1382.0 GAL/LOADING
                                         DEWAR LOADING  = 5704.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR            TOTAL          =  168389.6 LB/YEAR
  OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
  POWER          = 10.00               PERCENT DOWN TIME             =  1.0%
  LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  20.0
  LIQ. HYDROGEN  =  0.
```

------------------------- CASH FLOW ---------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 598533.60

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 28861.9	$ 4805.6	$ 632201.1	$ 294681.8	$ -337519.3
2	$ 31537.1	$ 5093.9	$ 36631.1	$ 294681.8	$ 258050.7
3	$ 34467.3	$ 5399.6	$ 39866.8	$ 294681.8	$ 254814.9
4	$ 37677.0	$ 5723.5	$ 43400.5	$ 294681.8	$ 251281.3
5	$ 41193.4	$ 6067.0	$ 47260.4	$ 294681.8	$ 247421.4
6	$ 45046.4	$ 6431.0	$ 51477.4	$ 294681.8	$ 243204.4
7	$ 49268.8	$ 6816.8	$ 56085.6	$ 294681.8	$ 238596.1
8	$ 53896.4	$ 7225.8	$ 61122.3	$ 294681.8	$ 233559.5
9	$ 58968.9	$ 7659.4	$ 66628.3	$ 294681.8	$ 228053.5
10	$ 64529.6	$ 8119.0	$ 72648.5	$ 294681.8	$ 222033.2
11	$ 70626.1	$ 8606.1	$ 79232.2	$ 294681.8	$ 215449.5
12	$ 77311.0	$ 9122.5	$ 86433.4	$ 294681.8	$ 208248.3
13	$ 84641.6	$ 9669.8	$ 94311.5	$ 294681.8	$ 200370.3
14	$ 92681.3	$ 10250.0	$ 102931.3	$ 294681.8	$ 191750.4
15	$ 101499.5	$ 10865.0	$ 112364.5	$ 294681.8	$ 182317.2
	$ 872206.5	$ 111855.0	$ 1582595.1	$ 4420226.5	$ 2837631.5

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 2.838 MILLION DOLLARS

```
-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  2.526 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .492 MILLION LBS
TOTAL NITROGEN EXPENDED       =  3.127 MILLION LBS
TOTAL WATER EXPENDED          = 14.082 MILLION GALS
TOTAL POWER EXPENDED          =  9.400 MILLION KW-HR
```

- LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % ᴗ DELTA

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 275821.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.20) $ 598533.60

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2122.0 GAL/LOADING
DEWAR LOADING = 8848.0 GAL/LOADING
TOTAL = 214084.1 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES,PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 598533.60

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 26656.8	$ 4805.6	$ 629996.0	$ 374647.1	$ -255348.9
2	$ 29111.6	$ 5093.9	$ 34205.5	$ 374647.1	$ 340441.6
3	$ 31799.1	$ 5399.6	$ 37198.7	$ 374647.1	$ 337448.4
4	$ 34742.0	$ 5723.5	$ 40465.6	$ 374647.1	$ 334181.6
5	$ 37965.0	$ 6067.0	$ 44031.9	$ 374647.1	$ 330615.2
6	$ 41495.2	$ 6431.0	$ 47926.1	$ 374647.1	$ 326721.0
7	$ 45362.4	$ 6816.8	$ 52179.2	$ 374647.1	$ 322467.9
8	$ 49599.4	$ 7225.8	$ 56825.2	$ 374647.1	$ 317821.9
9	$ 54242.1	$ 7659.4	$ 61901.5	$ 374647.1	$ 312745.6
10	$ 59330.1	$ 8119.0	$ 67449.1	$ 374647.1	$ 307198.0
11	$ 64906.8	$ 8606.1	$ 73512.9	$ 374647.1	$ 301134.2
12	$ 71019.7	$ 9122.5	$ 80142.1	$ 374647.1	$ 294505.0
13	$ 77721.2	$ 9669.8	$ 87391.0	$ 374647.1	$ 287256.1
14	$ 85068.9	$ 10250.0	$ 95318.9	$ 374647.1	$ 279328.3
15	$ 93125.8	$ 10865.0	$ 103990.8	$ 374647.1	$ 270656.3
	$ 802146.1	$ 111855.0	$ 1512534.7	$ 5619706.7	$ 4107172.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.107 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.211 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 1.230 MILLION LBS
TOTAL NITROGEN EXPENDED = 2.321 MILLION LBS
TOTAL WATER EXPENDED = 14.082 MILLION GALS
TOTAL POWER EXPENDED = 9.400 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 2 NO VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % $ DELTA

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.20) $ 832706.40

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 2696.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 243613.7 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 832706.40

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 51862.7	$ 4805.6	$ 889374.7	$ 426324.0	$ -463050.7
2	$ 56829.1	$ 5093.9	$ 61923.0	$ 426324.0	$ 364401.0
3	$ 62278.8	$ 5399.6	$ 67678.4	$ 426324.0	$ 358645.6
4	$ 68259.5	$ 5723.5	$ 73983.1	$ 426324.0	$ 352340.9
5	$ 74823.5	$ 6067.0	$ 80890.5	$ 426324.0	$ 345433.5
6	$ 82028.2	$ 6431.0	$ 88459.2	$ 426324.0	$ 337864.8
7	$ 89936.7	$ 6816.8	$ 96753.5	$ 426324.0	$ 329570.5
8	$ 98618.3	$ 7225.6	$ 105844.2	$ 426324.0	$ 320479.8
9	$ 108149.4	$ 7659.4	$ 115808.8	$ 426324.0	$ 310515.2
10	$ 118613.8	$ 8119.0	$ 126732.7	$ 426324.0	$ 299591.3
11	$ 130103.6	$ 8606.1	$ 138709.7	$ 426324.0	$ 287614.3
12	$ 142720.0	$ 9122.5	$ 151842.5	$ 426324.0	$ 274481.5
13	$ 156574.5	$ 9669.8	$ 166244.3	$ 426324.0	$ 260079.7
14	$ 171789.3	$ 10250.0	$ 182039.3	$ 426324.0	$ 244284.7
15	$ 188499.1	$ 10865.0	$ 199364.1	$ 426324.0	$ 226959.9
	$ 1601086.5	$ 111855.0	$ 2545647.9	$ 6394860.0	$ 3849212.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.849 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM = 3.654 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = 0. MILLION LBS
TOTAL NITROGEN EXPENDED = 7.059 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

```
    - LIFE CYCLE COST ------SYSTEM 2  5% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % → DELTA

CAPITAL INVESTMENT COST             OPERATING COST
  EQUIP AND MATL= $  470965.00        LABOR TIME=  8.0 HR/WEEK
  DETAILED DESIGN=$   47134.00        LABOR RATE= 12.00 $/HR
  FABRICATION    =$  123940.00        POWER RATE=  .024 $/KW-HR
  INSTALLATION   =$   51883.00        LN2 RATE  =  .041 $/LB
                     -----------      WATER RATE= .0003 $/GAL
  TOTAL * (1.20)  $  832706.40

MAINTENANCE COST DATA               SAVINGS DATA
  LABOR TIME=  6.9 HR/WEEK            HYDROGEN RELIQUEFIED
  LABOR RATE= 12.00 $/HR               NORMAL BOILOFF =  400.0 GAL/DAY
  MATERIALS =  500.00 $/YEAR           SHUTTLE LAUNCH = 3326.0 GAL/LOADIN
                                       DEWAR LOADING  =10784.0 GAL/LOADIN
ESCALATION RATES,PERCENT/YEAR          TOTAL          =  251025.5 LB/YEAR
  OPERATING LABOR=  6.00              LIQ HYDROGEN COST=  1.75 $/LB
  MAINTEN. LABOR =  6.00
  MAINTEN. MATL  =  6.00            OPERATIONAL PARAMETERS
  POWER          = 10.00              PERCENT DOWN TIME              =  1.0%
  LIQ NITROGEN   = 10.00              NO. OF SHUTTLE LAUNCHES/YEAR=  20.0
  WATER          =  6.00              NO. OF DEWAR LOADINGS/YR      =  20.0
  LIQ. HYDROGEN  =  0.

------------------------ CASH FLOW --------------------------------
          TOTAL CAPITAL INVESTMENT COST = $  832706.40
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50954.8	$ 4805.6	$ 888466.8	$ 439294.7	$ -449172.1
2	$ 55830.3	$ 5093.9	$ 60924.3	$ 439294.7	$ 378370.4
3	$ 61180.2	$ 5399.6	$ 66579.8	$ 439294.7	$ 372714.9
4	$ 67051.1	$ 5723.5	$ 72774.7	$ 439294.7	$ 366520.0
5	$ 73494.2	$ 6067.0	$ 79561.2	$ 439294.7	$ 359733.5
6	$ 80566.0	$ 6431.0	$ 86997.0	$ 439294.7	$ 352297.7
7	$ 88328.2	$ 6816.8	$ 95145.1	$ 439294.7	$ 344149.6
8	$ 96849.0	$ 7225.8	$ 104074.9	$ 439294.7	$ 335219.8
9	$ 106203.2	$ 7659.4	$ 113862.6	$ 439294.7	$ 325432.1
10	$ 116473.0	$ 8119.0	$ 124591.9	$ 439294.7	$ 314702.8
11	$ 127748.7	$ 8606.1	$ 136354.7	$ 439294.7	$ 302939.9
12	$ 140129.6	$ 9122.5	$ 149252.1	$ 439294.7	$ 290042.6
13	$ 153725.0	$ 9669.8	$ 163394.8	$ 439294.7	$ 275899.8
14	$ 168654.9	$ 10250.0	$ 178904.9	$ 439294.7	$ 260389.8
15	$ 185051.3	$ 10865.0	$ 195916.3	$ 439294.7	$ 243378.4
	$ 1572239.7	$ 111855.0	$ 2516801.1	$ 6589420.4	$ 4072619.2

```
PAY BACK OCCURS DURING YEAR  3
NET SAVINGS OVER 15 YEARS = 4.073 MILLION DOLLARS

-------------- IN 15 YEARS ------------------
TOTAL H2 SAVED WITH SYSTEM    =  3.765 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =  6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =   .104 MILLION LBS
TOTAL NITROGEN EXPENDED       =  6.727 MILLION LBS
TOTAL WATER EXPENDED          = 25.344 MILLION GALS
TOTAL POWER EXPENDED          = 16.919 MILLION KW-HR
```

ORIGINAL PAGE IS
OF POOR QUALITY

- LIFE CYCLE COST ------SYSTEM 2 10% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % ∪ DELTA

CAPITAL INVESTMENT COST
- EQUIP AND MATL= $ 470965.00
- DETAILED DESIGN=$ 47134.00
- FABRICATION =$ 123940.00
- INSTALLATION =$ 51883.00
- TOTAL * (1.20) $ 832706.40

OPERATING COST
- LABOR TIME= 8.0 HR/WEEK
- LABOR RATE= 12.00 $/HR
- POWER RATE= .024 $/KW-HR
- LN2 RATE = .041 $/LB
- WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
- LABOR TIME= 6.9 HR/WEEK
- LABOR RATE= 12.00 $/HR
- MATERIALS = 500.00 $/YEAR

ESCALATION RATES, PERCENT/YEAR
- OPERATING LABOR= 6.00
- MAINTEN. LABOR = 6.00
- MAINTEN. MATL = 6.00
- POWER = 10.00
- LIQ NITROGEN = 10.00
- WATER = 6.00
- LIQ. HYDROGEN = 0.

SAVINGS DATA
- HYDROGEN RELIQUEFIED
  - NORMAL BOILOFF = 400.0 GAL/DAY
  - SHUTTLE LAUNCH = 3884.0 GAL/LOADING
  - DEWAR LOADING =10784.0 GAL/LOADING
  - TOTAL = 257590.3 LB/YEAR
- LIQ HYDROGEN COST= 1.75 $/LB

OPERATIONAL PARAMETERS
- PERCENT DOWN TIME = 1.0%
- NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
- NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 832706.40

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 50476.8	$ 4805.6	$ 887988.8	$ 450783.0	$ -437205.8
2	$ 55304.6	$ 5093.9	$ 60398.5	$ 450783.0	$ 390384.5
3	$ 60601.9	$ 5399.6	$ 66001.4	$ 450783.0	$ 384781.6
4	$ 66414.9	$ 5723.5	$ 72138.5	$ 450783.0	$ 378644.6
5	$ 72794.4	$ 6067.0	$ 78861.4	$ 450783.0	$ 371921.6
6	$ 79796.2	$ 6431.0	$ 86227.2	$ 450783.0	$ 364555.9
7	$ 87481.4	$ 6816.8	$ 94298.3	$ 450783.0	$ 356484.7
8	$ 95917.6	$ 7225.8	$ 103143.4	$ 450783.0	$ 347639.6
9	$ 105178.6	$ 7659.4	$ 112838.0	$ 450783.0	$ 337945.0
10	$ 115345.9	$ 8119.0	$ 123464.9	$ 450783.0	$ 327318.2
11	$ 126508.9	$ 8606.1	$ 135115.0	$ 450783.0	$ 315668.0
12	$ 138765.9	$ 9122.5	$ 147888.3	$ 450783.0	$ 302894.7
13	$ 152224.9	$ 9669.8	$ 161894.7	$ 450783.0	$ 288688.3
14	$ 167004.8	$ 10250.0	$ 177254.8	$ 450783.0	$ 273528.2
15	$ 183236.1	$ 10865.0	$ 194101.1	$ 450783.0	$ 256681.9
	$ 1557052.9	$ 111855.0	$ 2501614.3	$ 6761745.3	$ 4260131.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.260 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM	=	3.864 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	=	6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	=	.209 MILLION LBS
TOTAL NITROGEN EXPENDED	=	6.552 MILLION LBS
TOTAL WATER EXPENDED	=	25.344 MILLION GALS
TOTAL POWER EXPENDED	=	16.919 MILLION KW-HR

- LIFE CYCLE COST ------SYSTEM 2 25% VENTING
FOUR COMPRESSORS, 20 LAUNCHES, 48 HRS 20 % , DELTA

CAPITAL INVESTMENT COST
EQUIP AND MATL= $ 470965.00
DETAILED DESIGN=$ 47134.00
FABRICATION =$ 123940.00
INSTALLATION =$ 51883.00

TOTAL * (1.20) $ 832706.40

OPERATING COST
LABOR TIME= 8.0 HR/WEEK
LABOR RATE= 12.00 $/HR
POWER RATE= .024 $/KW-HR
LN2 RATE = .041 $/LB
WATER RATE= .0003 $/GAL

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 5374.0 GAL/LOADING
DEWAR LOADING =10784.0 GAL/LOADING
TOTAL = 275119.8 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------
TOTAL CAPITAL INVESTMENT COST = $ 832706.40

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 49893.2	$ 4805.6	$ 887405.2	$ 481459.7	$ -405945.5
2	$ 54662.6	$ 5093.9	$ 59756.5	$ 481459.7	$ 421703.2
3	$ 59895.7	$ 5399.6	$ 65295.2	$ 481459.7	$ 416164.5
4	$ 65638.1	$ 5723.5	$ 71361.6	$ 481459.7	$ 410098.1
5	$ 71939.9	$ 6067.0	$ 78006.9	$ 481459.7	$ 403452.8
6	$ 78856.2	$ 6431.0	$ 85287.2	$ 481459.7	$ 396172.5
7	$ 86447.5	$ 6816.8	$ 93264.3	$ 481459.7	$ 388195.4
8	$ 94780.3	$ 7225.8	$ 102006.1	$ 481459.7	$ 379453.6
9	$ 103927.5	$ 7659.4	$ 111586.9	$ 481459.7	$ 369872.8
10	$ 113969.7	$ 8119.0	$ 122088.7	$ 481459.7	$ 359371.0
11	$ 124995.1	$ 8606.1	$ 133601.2	$ 481459.7	$ 347858.5
12	$ 137100.7	$ 9122.5	$ 146223.2	$ 481459.7	$ 335236.6
13	$ 150393.2	$ 9669.8	$ 160063.0	$ 481459.7	$ 321396.7
14	$ 164989.9	$ 10250.0	$ 175239.9	$ 481459.7	$ 306219.8
15	$ 181019.8	$ 10865.0	$ 191884.8	$ 481459.7	$ 289574.9
	$ 1538509.5	$ 111855.0	$ 2483070.9	$ 7221896.0	$ 4738825.1

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 4.739 MILLION DOLLARS

-------------- IN 15 YEARS -------------------
TOTAL H2 SAVED WITH SYSTEM = 4.127 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM = 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM = .522 MILLION LBS
TOTAL NITROGEN EXPENDED = 6.338 MILLION LBS
TOTAL WATER EXPENDED = 25.344 MILLION GALS
TOTAL POWER EXPENDED = 16.919 MILLION KW-HR

APPENDIX E

Implementation Plan, Thermal Cycle Analysis with Below Ambient Pressure in the Condenser, and Life Cycle Cost Analysis for Test Cases with Two Compressors, Twenty-Five Percent Venting, and Eight and Twelve Launches Per Year

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CONTENTS

FIGURES

TABLES

INTRODUCTION

Appendix E reports the results of studies performed in accordance with a contract ammendment to: 1) develop an implementation plan for design, construction, test and installation of the reliquefier system; 2) run the thermal cycle analyzer computer program for test cases with below ambient pressure in the condenser; and 3) run the life cycle cost analysis computer program for test cases with two compressors, twenty-five percent venting, and 8 and 12 launches per year.

A Statement of Work is presented that identifies specific tasks required to implement the liquefier system. Equipment lists are updated and documented in greater detail identifying specific suppliers, delivery times and costs. The overall capital investment cost is revised to include performance testing prior to installation and the design configuration presented in Section IX of the basic report. An implementation schedule was developed that shows that the reliqueifier system can be incorporated at KSC and completely checked out within a period of 14 months.

The lowest attainable condenser reservoir pressure with an unaided compressor is about 11 psia. Test cases were run on the thermal analyzer computer program at 11 psia, both with and without the ejector system. The results indicate no appreciable change in component sizing or system performance.

IMPLEMENTATION PLAN

I. STATEMENT OF WORK

The inter-relationship of tasks required for implementation of the LH_2 Reliquefaction System at KSC is depicted in Figure E-1. This effort can be grouped into nine basic work tasks:

Task 1 - System Design
Task 2 - Procurement and Subcontract Administration
Task 3 - Fabrication & System Assembly for Test
Task 4 - System Performance Test
Task 5 - Acceptance Test
Task 6 - Pack and Ship
Task 7 - Facility Modification and Equipment Installation
Task 8 - System Startup and Checkout
Task 9 - Documentation

An outline identifying the specific work elements required by dicipline for each task is provided as follows:

Task 1 - System Design

1. Mechanical Design

    a. Cold Box Design Specification
    b. Compressor Design Specification
    c. Dewar Structural Modification Details
    d. Dewar Penetration Design
    e. Cold Box Installation Design
    f. Compressor Installation Design
    g. Piping System Design

2. Electrical Design

    a. Control Schematic
    b. Wiring List/Wiring Identification Sheet
    c. Control Wiring Drawing
    d. Power Wiring Diagram
    e. Conduit Drawing
    f. Control Panel Drawing
    g. Liquid Level Installation Details
    h. Temperature Sensor/Readout System Design

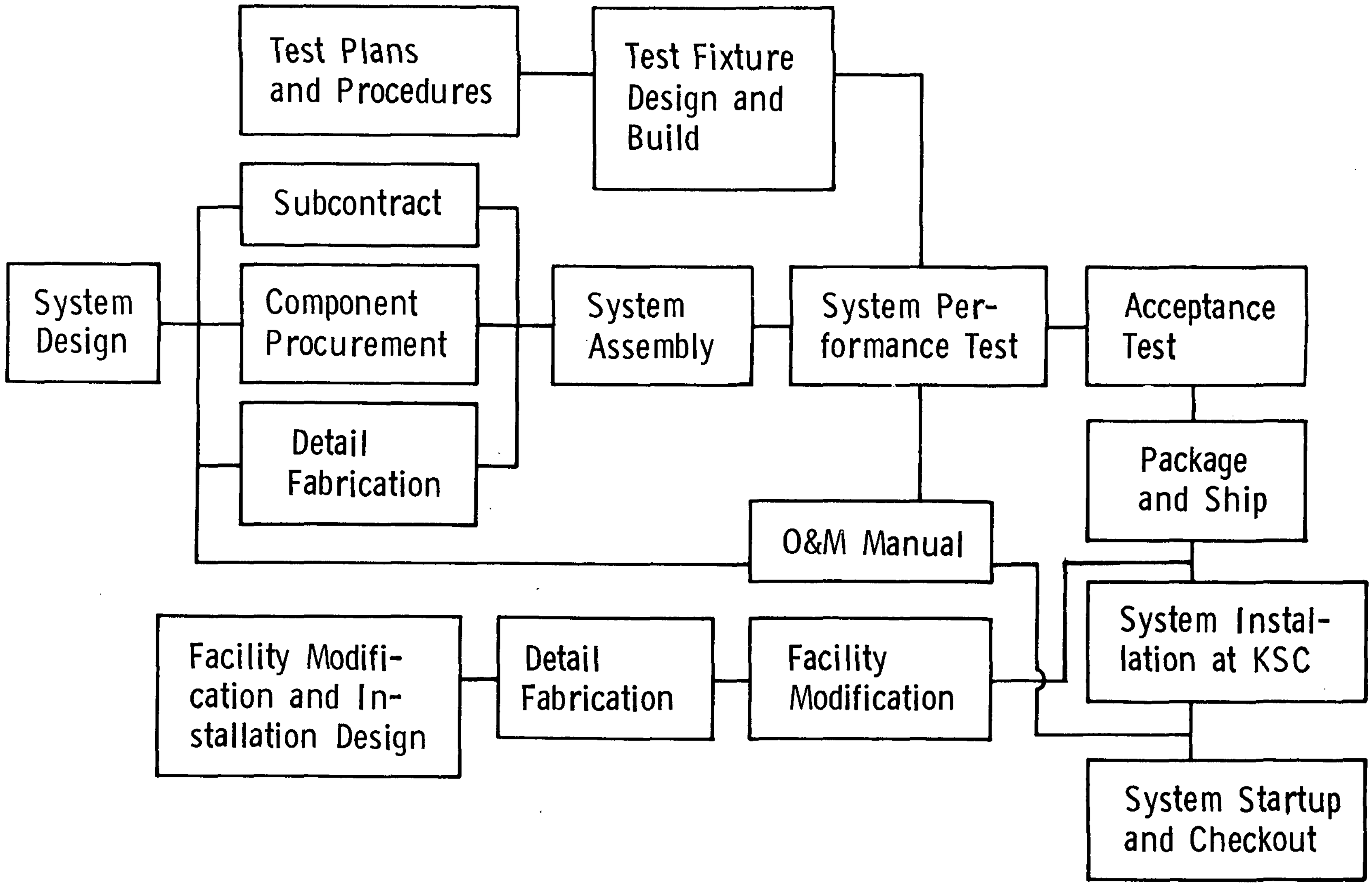

FIGURE E-1 - IMPLEMENTATION TASKS

I. STATEMENT OF WORK (cont'd)

Task 2 - Procurement and Subcontract Administration

1. Purchase raw material and components.
2. Select subcontractors for Cold Box and Compressors.
3. Maintain liaison and coordination with subcontractors.
4. Receive, inspect, and stage raw material and components.

Task 3 - Fabrication and Assembly for Test

1. Detail fabrication
2. Reliquefaction System Assembly

Task 4 - System Performance Test

1. Test Engineering

    a. Test planning and coordination
    b. Facility Checkout and Validation Procedure
    c. Performance Test Procedure
    d. Supervise Facility Checkouts and Performance Testing

2. Mechanical Design

    a. Design Test Facility
    b. Provide liaison and support during test facility build and test

3. Electrical Design

    a. Design instrumentation system and controls
    b. Provide technical support during testing

4. Test Operations

    a. Build test fixture and Instrumentation
    b. Conduct testing

5. Safety

    a. Review and approve test plans and procedures
    b. Conduct safety analysis of test facility

Task 5 - Acceptance Test

1. Test Engineering

    a. Write acceptance test procedure
    b. Supervise acceptance test

I. STATEMENT OF WORK (cont'd)

Task 5 - Acceptance Test (cont'd)

2. Operations

   a. Assemble test setup
   b. Conduct acceptance test

3. Quality

   a. Monitor and approve testing
   b. Execute DD-250 documentation

Task 6 - Pack and Ship

1. Package equipment for shipment
2. Coordinate shipping

Task 7 - Facility Modification and Equipment Installation

1. Mechanical Design - Technical support during installation
2. Electrical Design - Technical support during installation
3. Operations

   a. Incorporate Dewar Structural Modifications
   b. Incorporate Dewar Penetration Modifications
   c. Cold Box Installation
   d. Compressor Installation
   e. Piping Installation
   f. Mechanical & Electrical Component Installation
   g. Interconnecting Piping and Wiring Installation

Task 8 - System Startup and Checkout

1. Test Engineering

   a. Write Checkout Procedure
   b. Supervise Checkout Activities

2. Operations

   a. Conduct system leak checks and functionals
   b. Conduct system startup and operational checks

Task 9 - Documentation

1. Conduct Design Reviews
2. Write Test Reports
3. Produce O&M Manual

II. EQUIPMENT AVAILABILITY AND COSTS

All items of equipment required for the H_2 Reliquefaction system are identified along with delivery times and estimated cost in Table E-1. Costs and delivery data were obtained by contact with reputable suppliers. A detail cost and schedule analysis for the cold box was conducted by Cryenco under contract to Martin Marietta. A firm quotation for the compressors could not be obtained without a complete design specification. Several compressor contractors expressed interest and correspondence indicating technical, price and schedule data was received.

As noted in Table E-1, all items except the compressors and cold box are standard commercial equipment. The compressor is assembled from standard components consistent with system size requirements and requires no new development. The cold box is not standard equipment, but Cryenco has successfully completed a number of hydrogen reliquefier/refrigeration cold box projects similar to the design proposed. Thus, it is believed that a LH_2 reliquefaction system can be successfully implemented at LC-39A and B with essentially no technical risk.

TABLE E-1 - EQUIPMENT LIST

TASK II - EQUIPMENT

QTY	ITEM	SUPPLIER/PART NO.	DELIVERY	COST
1	Cold Box	Cryenco	6 Mo.	$ 56,500
2	Compressor	RIX Industries	5 Mo.	100,000
1	DEOXO Unit	Engle Hard Industries	10 Wk.	6,680
1	Dehydrating Unit	Electric Dryer	16 Wk.	5,642
1	LH_2 Fill Valve	Annin/Mod. 2620 with flanges and extension	4 Wk.	1,040
1	LN_2 ByPass Valve	Annin/3-way Mod. 2623 with raised faced flanges and extension	4 Wk.	1,304
1	Valve, 1"-1500 #R.J.	Annin/Mod. 4520	4 Wk.	1,596
1	Valve, 1"-150 #R.J.	Annin/Mod. 2620	4 Wk.	924
2	Valve, 2"-150 #R.J.	Annin/Mod. 2610	4 Wk.	1,680
6	Valve	Nupro/SS-4BK-TSW	5 Wk.	394
2	Valve, 1"-1500 #R.J.	Annin/Mod. 4510	8 Wk.	2,736
1	Pressure Relief Valve	Anderson Greenwood/81S88-8		325
1	Pressure Relief Valve	Anderson Greenwood/81S88-6		250
2	Vacuum Valve	VEECO/VA-110	2 Wk.	450
1	Vacuum Pump	Welch/1402W01	2 Wk.	765
1	Pressure Regulator (Handloader for Purge System)	Grove/10927AP2A	4 Wk.	250
1	Pressure Gage	Marsh/5242	4 Wk.	141
2	Check Valve	Circle Seal/249T-16TT	3 Wk.	373
1	Pressure Regulator	Masoneilan 77 Series	6 Wk.	58
4	Purge Orifice	KSC/75M04165	8 Wk.	332
4	Purge Bleed	KSC/75M02048	8 Wk.	148
1	Bellows, 6" I.D.	Metal Bellows/1000-0601M-6-2	6 Wk.	518
4	Turnbuckle	McMaster Carr/3022T28	2 Wk.	180
4	3-Mode Controller	EMC/Model 6812	10 Wk	1,870
3	Pressure Transducer	Bourns/79K03438-G-1-N-18	14 Wk.	2,738
5	I.P. Valve Controller	Masoneilan 8005	8 Wk.	1,250
1	Control Console	Markhon/Frame 41J29	10 Wk.	178
		/L Side J9LK	10 Wk.	26
		/R Side J9RK	10 Wk.	26
		/Rear Door J2AV	10 Wk.	50
		/Top 29TV	10 Wk.	16
		/Base MB 24-25-2	10 Wk.	45
		/Power Strip PS36	10 Wk.	15
7	Platinum Temp Sensors	Rosemont/MA172	8 Wk.	1,519
1	Low Temp LN_2 Float Switch	Revere/F75720	6 Wk.	304

TABLE E-1 - EQUIPMENT LIST (cont'd)

TASK 2 - EQUIPMENT (cont'd)

QTY	ITEM	SUPPLIER/PART NO.	DELIVERY	COST
2	Low Temp. LN_2 Level Sensor	Scientific Instr. Inc./ 40-2-6	12 Wk.	3,500
1	Penetration Connector	Deutch /DM5623-37-2PP	8 Wk.	229
1	Internal Connector	Deutch /13084-37-2S-5020	8 Wk.	140
1	External Connector	Deutch /D507-37-2S-059	8 Wk.	126
1	Temp. Measurement and Display	Rosemont/2510	6 Wk.	2,500
1	Gauge Unit	Bendix/5506945-2	6 Wk.	1,000
2	Cables, 100 ft. Long	Bendix/277131-S	6 Wk.	52
2	Gauge Weld Adapters	Bendix/268891-8	6 Wk.	86
1	Control Assembly	Bendix/277228-GPH-D10A	6 Wk.	128
X	Misc. El. Supplies		6 Wk.	500
1	Enclosure	Hoffman/Type 12 with panel and Reinforced Door	12 Wk.	700
X	Solid Copper Wire, Grounding		12 Wk.	50
X	Grounding Clamps		12 Wk.	200
1	Junction Box, E.P. Copper Wire #20, 4 Cond/Power Cable		8 Wk.	200
2 Gal.	Beige Paint with Primer & Thinner		6 Wk.	55
1 Set	Engraved Tags		6 Wk.	100
10	Terminal Strips with Markers		6 Wk.	76
10	Relay Sockets	Curtis/C458	6 Wk.	16
10	Relays	P&B/KRP11D	6 Wk.	150
1	Power Supply	Power One/F24-12	6 Wk.	150
7	Thermowells		8 Wk.	438
2	Pressure Switches	779KXXXXX	14 Wk.	1,825
1	LH_2 Liquid Sensor	Simmonds/	18 Wk.	1,600
1	Power Transformer 480/110		8 Wk.	150
1	Lightning Rod Hardware		6 Wk.	200
1	Sealing Compound		6 Wk.	50
1	Circuit Breaker		6 Wk.	200
1	Contractor, E.P.		8 Wk.	1,000
2	Motor Starter, E.P.	Killark/	8 Wk.	2,264
2	Flexible Coupling, E. P.	Appleton/	6 Wk.	300
1000	Crimp Lugs		6 Wk.	100
500 ft	Conduit, 3/4" with Coupling, Rigid Aluminum		6 Wk.	800
X	Conduit Fittings		6 Wk.	800

TABLE E-1 - EQUIPMENT LIST (cont'd)

TASK 2 - EQUIPMENT (cont'd)

QTY	ITEM	SUPPLIER/PART NO.	DELIVERY	COST
150 ft	Pipe, 2"-Sch 40S, Ty 304L		2 Wk.	$ 969
250 ft	Pipe 31"-Sch 40S, Type 304L		2 Wk.	865
8	Flange, 2"-150#/W.N. R.J., Type 304L		2 Wk.	445
8	Flange, 1"-150#/W.N. R.J., Type 304L		2 Wk.	330
16	Studs, 7/8"x5, Type 304		2 Wk.	56
4	Flange Gasket	R/R-22	2 Wk.	103
32	Studs, Type 304		2 Wk.	300
4	Flange Gasket	R/R-16	2 Wk.	73
4	Pipe Elbow, 1"Sch 40, 90° Type 304		2 Wk.	27
4	Pipe Elbow, 2" Sch 40, 90°, Type 304		2 Wk.	50
2	Pipe Tee, 1" Sch 40, Type 304		2 Wk.	38
2	Pipe Tee, 2" Sch 40, Type 304		2 Wk.	72
X	AN Fittings	KSC Type	8 Wk	1,000
1	Flexible Hose, 1"x36", 2,200 psi	Metal Bellows	12 Wk.	800
1	Flexible Hose, 2"x36", 750 psi	Metal Bellows/5501-32G-0360-W-T-T	12 Wk.	1,160
100 ft	Tubing, 1/2" O.D. x .035 wall, Type 304			309
X	Wash Primer	Mobile Chemical/MIL-P-15328B	4 Wk.	37
X	Vinyl Red Lead Primer	Mobile Chemical/MIL-P-15929C	4 Wk.	369
X	Vinyl Paint (White)	Mobile Chemical/SSPC #9	4 Wk.	383
1	Steel PL , 3/4" x 48" x 120"	/ASTM A-36	1 Wk.	303
12 ft	Tube, 6" OD x .065" x 12', Type 304		2 Wk.	224
150 ft	Tube, 3/8" OD x .035 Type 304		2 Wk.	936
200 ft	Tube, 1/2" OD x .034, Type 304		2 Wk.	618
			Total	$219,475

TABLE E-1 - EQUIPMENT LIST (cont'd)

TASK 4 - EQUIPMENT

QTY	ITEM	SUPPLIER/PART NO.	DELIVERY	COST
MECHANICAL				
2	Flanged & Dished Head 48" O.D. x 10 G.A., Type 304, ASME S.F.		6 Wk	$ 466
1	S.S. Sheet, 10 Ga. (.135) x 48"x144"		2 Wk.	302
50 ft	Pipe, 1" Sch 40 Type 304L		2 Wk.	173
100 ft	Tubing, 1/2 O.D.x .035, Type 304L		2 Wk.	309
4 ft	Tubing, 6"x.065, Type 304L		2 Wk.	75
340#	WF Beam 6"-8.5 lb		2 Wk.	100
50#	1/2 PL X 18" X 18"		2 Wk.	140
			Total	$1,565

ELECTRICAL

1	Heater	$ 438
	Chamber Penetrations	368
	Heater D.C. Supply	200
	LH_2 Liquid Sensor	210
	Total	$1,216

TABLE E-1 - EQUIPMENT LIST (cont'd)

TASK 7 - EQUIPMENT

1.	Crane Service and Tool Rental	$ 8,190
2.	Concrete	$ 2,200
		$10,390

III. IMPLEMENTATION SCHEDULE

The H_2 reliquefaction system can be incorporated into the hydrogen storage system at KSC within a period of fourteen months. Span times required for the specific implementation tasks are identified in Figure E-2, Implementation Schedule.

It is significant to note that the H_2 dewar would only be out of service for two months during installation, system startup and checkout activities.

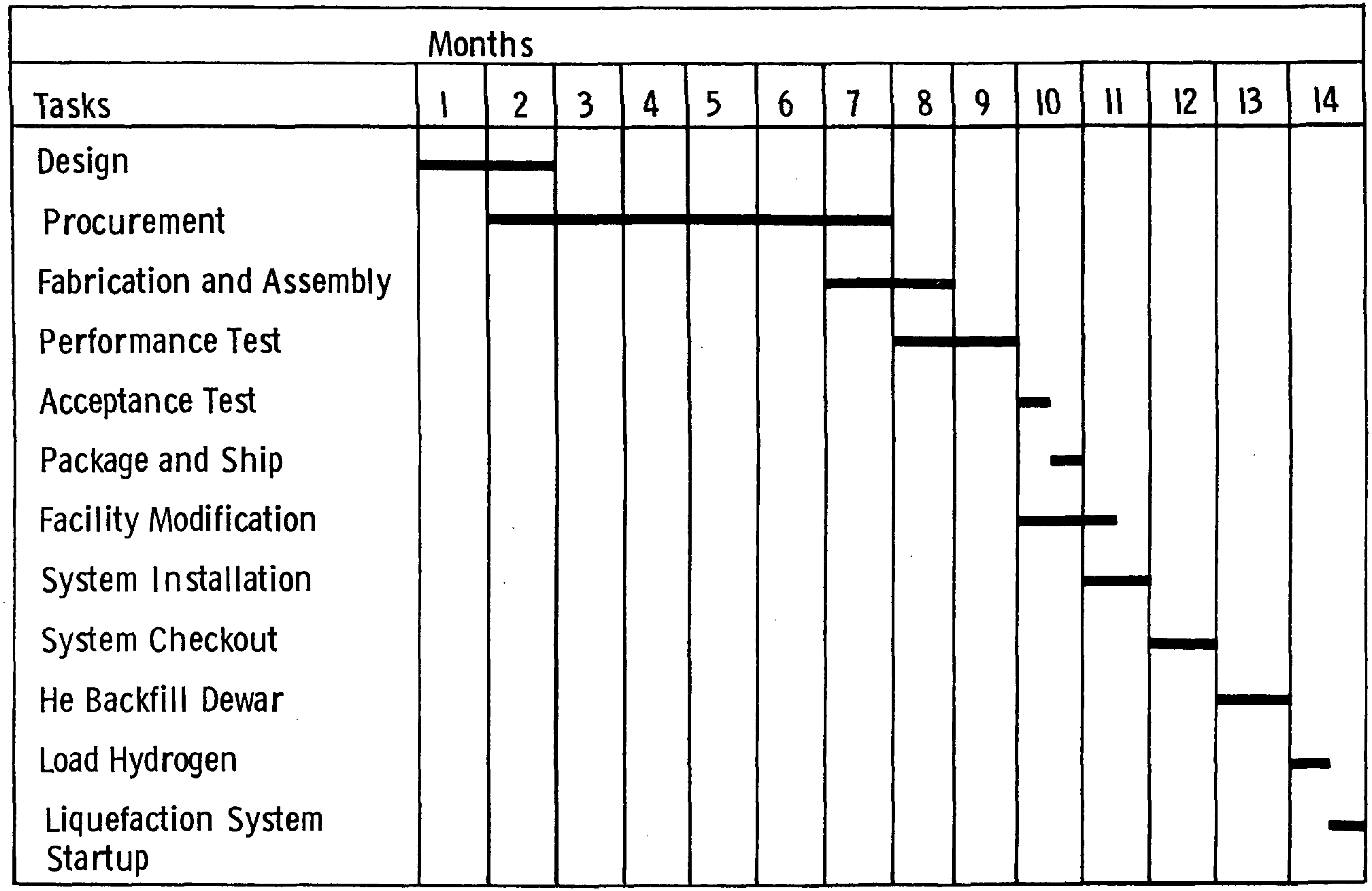

FIGURE E-2. IMPLEMENTATION SCHEDULE

IV. CAPITAL INVESTMENT

A detail estimate of the capital investment required to implement the hydrogen reliquefaction system at LC-39B was developed. The basis of estimate includes all direct labor required to implement the statement of work presented in Section I, material and component price quotations from reputable suppliers, labor rates and burdons in effect in January 1978. A summary of costs for each task identified in the statement of work is provided in Table E-2.

Table E-2. Estimate of Capital Investment Cost

Task 1, Design	$ 43,000
Task 2, Materials and Subcontract	334,000
Task 3, Fabrication and Assembly	28,000
Task 4, Performance Test	39,000
Task 5, Acceptance Test	8,000
Task 6, Pack and Ship	8,000
Task 7, Facility Modification and Installation	112,000
Task 8, Startup and Checkout	25,000
Task 9, Documentation and Reporting	10,000
Total	$607,000

V. LIFE CYCLE COST ANALYSIS

The life cycle cost analysis computer program was run for test cases consisting of two compressors, twenty-five percent venting and 8, 12, 16, and 20 launches per year. The results are plotted in Figure E-3 showing the savings in hydrogen and dollars as a function of the number of Shuttle launches per year. Copies of the computer results are provided in the following pages and tabulated below:

No. of Shuttle Launches	Savings ($\$ \times 10^6$)	Savings (Lb $H_2 \times 10^6$)	Payback
8	1.996	1.937	3 years
12	2.551	2.268	3 years
16	3.106	2.599	2 years
20	3.661	2.930	2 years

Savings are based on a 15 year shuttle launch program.

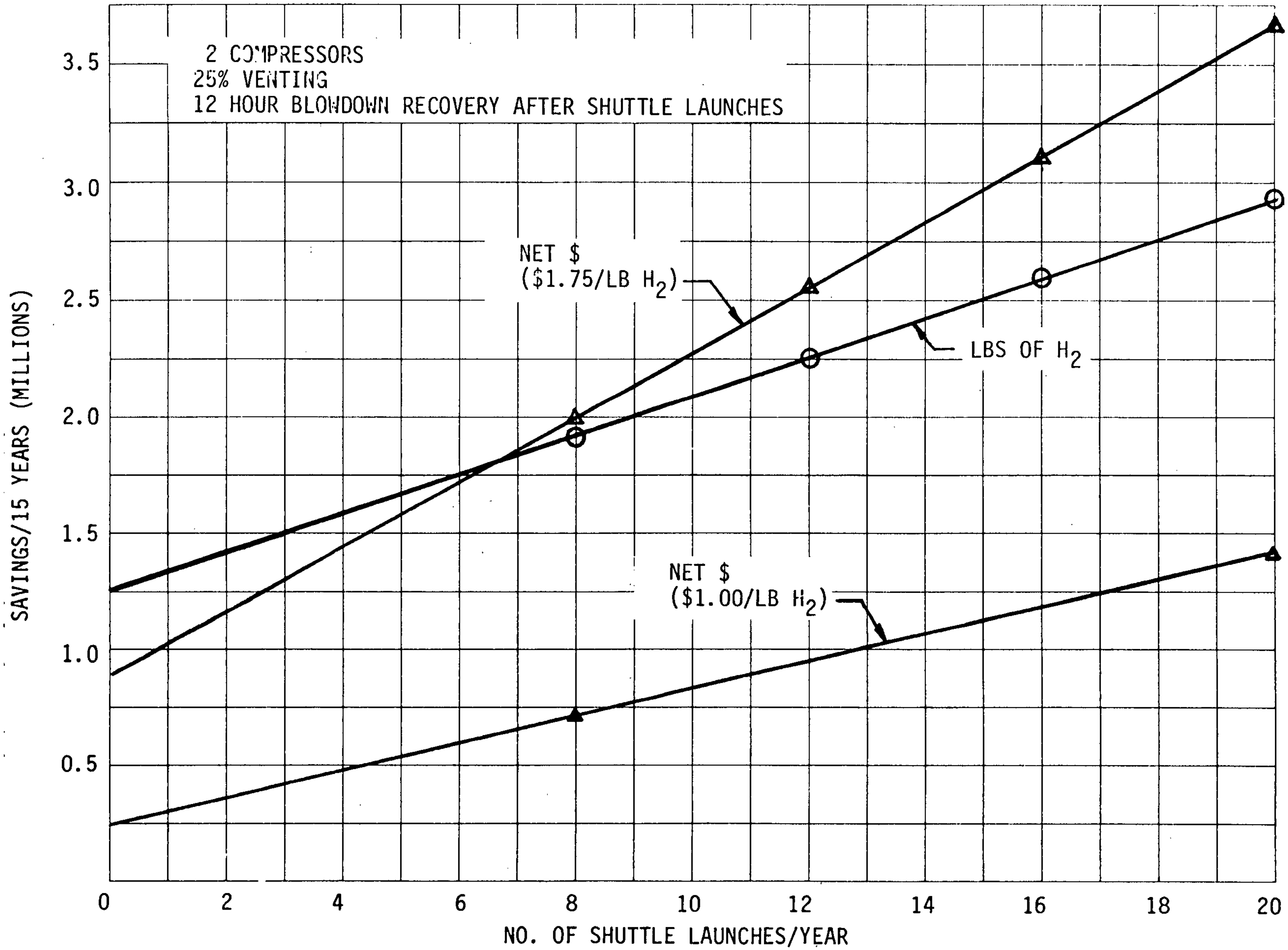

FIGURE E-3. PROGRAM COST AND HYDROGEN SAVINGS VERSUS NUMBER OF SHUTTLE LAUNCHES/YEAR

TABLE E-3 - LIFE CYCLE COST, EIGHT LAUNCHES PER YEAR

*CAPITAL INVESTMENT COST	
EQUIP AND MATL=	$ 295985.00
DETAILED DESIGN=	$ 69929.00
FABRICATION =	$ 74255.00
INSTALLATION =	$ 134831.00
TOTAL * (1.00)	$ 575000.00

OPERATING COST	
LABOR TIME=	8.0 HR/WEEK
LABOR RATE=	12.00 $/HR
POWER RATE=	.024 $/KW-HR
LN2 RATE =	.041 $/LB
WATER RATE=	.0003 $/GAL

MAINTENANCE COST DATA	
LABOR TIME=	6.9 HR/WEEK
LABOR RATE=	12.00 $/HR
MATERIALS =	500.00 $/YEAR

SAVINGS DATA	
HYDROGEN RELIQUEFIED	
NORMAL BOILOFF =	400.0 GAL/DAY
SHUTTLE LAUNCH =	530.5 GAL/LOADING
DEWAR LOADING =	8848.0 GAL/LOADING
TOTAL =	129159.7 LB/YEAR
LIQ HYDROGEN COST=	1.75 $/LB

ESCALATION RATES,PERCENT/YEAR	
OPERATING LABOR=	6.00
MAINTEN. LABOR =	6.00
MAINTEN. MATL =	6.00
POWER =	10.00
LIQ NITROGEN =	10.00
WATER =	6.00
LIQ. HYDROGEN =	0.

OPERATIONAL PARAMETERS	
PERCENT DOWN TIME =	1.0%
NO. OF SHUTTLE LAUNCHES/YEAR=	8.0
NO. OF DEWAR LOADINGS/YR =	8.0

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 1.996 MILLION DOLLARS

IN 15 YEARS		
TOTAL H2 SAVED WITH SYSTEM	= 1.937	MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	= 3.338	MILLION LBS
TOTAL H2 VENTED BY SYSTEM	= .416	MILLION LBS
TOTAL NITROGEN EXPENDED	= 2.539	MILLION LBS
TOTAL WATER EXPENDED	= 10.770	MILLION GALS
TOTAL POWER EXPENDED	= 7.190	MILLION KW-HR

CASH FLOW

TOTAL CAPITAL INVESTMENT COST = $ 575000.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 23652.2	$ 4805.6	$ 603457.8	$ 226027.7	$ -377430.1
2	$ 25809.2	$ 5093.9	$ 30903.1	$ 226027.7	$ 195124.6
3	$ 28169.3	$ 5399.6	$ 33568.9	$ 226027.7	$ 192458.8
4	$ 30752.2	$ 5723.5	$ 36475.7	$ 226027.7	$ 189552.0
5	$ 33579.3	$ 6057.0	$ 39636.3	$ 226027.7	$ 186391.4
6	$ 36674.3	$ 6431.0	$ 43105.2	$ 226027.7	$ 182922.5
7	$ 40062.9	$ 6916.8	$ 46879.8	$ 226027.7	$ 179147.9
8	$ 43773.8	$ 7225.8	$ 50999.6	$ 226027.7	$ 175028.1
9	$ 47837.9	$ 7659.4	$ 55497.3	$ 226027.7	$ 170530.4
10	$ 52289.7	$ 8119.0	$ 60408.7	$ 226027.7	$ 165619.0
11	$ 57166.8	$ 8606.1	$ 65772.9	$ 226027.7	$ 160254.8
12	$ 62510.5	$ 9122.5	$ 71632.9	$ 226027.7	$ 154394.8
13	$ 68366.1	$ 9669.8	$ 78035.9	$ 226027.7	$ 147991.8
14	$ 74783.6	$ 10250.0	$ 85033.6	$ 226027.7	$ 140994.1
15	$ 81817.6	$ 10865.0	$ 92682.6	$ 226027.7	$ 133345.0
	$ 707245.3	$ 111855.0	$ 1334100.3	$ 3390415.4	$ 1996315.1

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*NOTE: A capital investment cost of $575,000 was based on preliminary estimates. More detailed estimates, made later in the program, showed the required capital investment to be $607,000. This difference in estimated capital investment has negligible effect on the life cycle cost analysis.

TABLE E-4 - LIFE CYCLE COST, TWELVE LAUNCHES PER YEAR

```
TABLE      ------ LIFE CYCLE COST ------SYSTEM 1 25% VENTING
           TWO COMPRESSORS, 12 LAUNCHES, 12 HRS 15 YEAR LIFE

      *CAPITAL INVESTMENT COST              OPERATING COST
         EQUIP AND MATL= $  295985.00         LABOR TIME=  8.0 HR/WEEK
         DETAILED DESIGN=$   69929.00         LABOR RATE= 12.00 $/HR
         FABRICATION    =$   74255.00         POWER RATE=  .024 $/KW-HR
         INSTALLATION   =$  134831.00         LN2 RATE  =  .041 $/LB
                            ----------        WATER RATE= .0003 $/GAL
         TOTAL * (1.00)  $  575000.00

       MAINTENANCE COST DATA                SAVINGS DATA
         LABOR TIME=  6.9 HR/WEEK             HYDROGEN RELIQUEFIED
         LABOR RATE= 12.00 $/HR                 NORMAL BOILOFF =   400.0 GAL/DAY
         MATERIALS =  500.00 $/YEAR             SHUTTLE LAUNCH =   530.5 GAL/LOADING
                                                DEWAR LOADING  =  8848.0 GAL/LOADING
       ESCALATION RATES,PERCENT/YEAR            TOTAL          =  151225.9 LB/YEAR
         OPERATING LABOR=  6.00               LIQ HYDROGEN COST=  1.75 $/LB
         MAINTEN. LABOR =  6.00
         MAINTEN. MATL  =  6.00             OPERATIONAL PARAMETERS
         POWER          = 10.00               PERCENT DOWN TIME             =  1.0%
         LIQ NITROGEN   = 10.00               NO. OF SHUTTLE LAUNCHES/YEAR=  12.0
         WATER          =  6.00               NO. OF DEWAR LOADINGS/YR     =  12.0
         LIQ. HYDROGEN  =  0.

       ----------------------- CASH FLOW -------------------------------
                 TOTAL CAPITAL INVESTMENT COST = $  575000.00
```

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 24424.8	$ 4805.6	$ 604230.4	$ 264645.4	$ -339585.0
2	$ 26658.3	$ 5093.9	$ 31752.2	$ 264645.4	$ 232893.1
3	$ 29102.6	$ 5399.6	$ 34502.2	$ 264645.4	$ 230143.2
4	$ 31778.1	$ 5723.5	$ 37501.6	$ 264645.4	$ 227143.7
5	$ 34707.0	$ 6067.0	$ 40773.9	$ 264645.4	$ 223871.4
6	$ 37913.8	$ 6431.0	$ 44344.8	$ 264645.4	$ 220300.5
7	$ 41425.6	$ 6816.8	$ 48242.4	$ 264645.4	$ 216402.9
8	$ 45271.7	$ 7225.8	$ 52497.5	$ 264645.4	$ 212147.8
9	$ 49484.6	$ 7659.4	$ 57144.0	$ 264645.4	$ 207501.3
10	$ 54100.0	$ 8119.0	$ 62219.0	$ 264645.4	$ 202426.4
11	$ 59157.0	$ 8606.1	$ 67763.1	$ 264645.4	$ 196882.3
12	$ 64698.4	$ 9122.5	$ 73820.9	$ 264645.4	$ 190824.5
13	$ 70771.5	$ 9669.8	$ 80441.4	$ 264645.4	$ 184204.0
14	$ 77428.2	$ 10250.0	$ 87678.2	$ 264645.4	$ 176967.2
15	$ 84725.3	$ 10865.0	$ 95590.3	$ 264645.4	$ 169055.1
	$ 731646.9	$ 111855.0	$ 1418501.9	$ 3969680.3	$ 2551178.4

```
PAY BACK OCCURS DURING YEAR
NET SAVINGS OVER 15 YEARS = 2.551 MILLION DOLLARS

------------- IN 15 YEARS -----------------
TOTAL H2 SAVED WITH SYSTEM    =   2.268 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM  =   4.363 MILLION LBS
TOTAL H2 VENTED BY SYSTEM     =    .627 MILLION LBS
TOTAL NITROGEN EXPENDED       =   2.483 MILLION LBS
TOTAL WATER EXPENDED          =  11.623 MILLION GALS
TOTAL POWER EXPENDED          =   7.759 MILLION KW-HR
```

TABLE E-5. LIFE CYCLE COST, SIXTEEN LAUNCHES PER YEAR

TABLE

------ LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 16 LAUNCHES, 12 HRS 15 YEAR LIFE

*CAPITAL INVESTMENT COST		OPERATING COST	
EQUIP AND MATL=	$ 295985.00	LABOR TIME=	8.0 HR/WEEK
DETAILED DESIGN=	$ 69929.00	LABOR RATE=	12.00 $/HR
FABRICATION =	$ 74255.00	POWER RATE=	.024 $/KW-HR
INSTALLATION =	$ 134831.00	LN2 RATE =	.041 $/LB
	-----------	WATER RATE=	.0003 $/GAL
TOTAL * (1.00)	$ 575000.00		

MAINTENANCE COST DATA		SAVINGS DATA	
LABOR TIME=	6.9 HR/WEEK	HYDROGEN RELIQUEFIED	
LABOR RATE=	12.00 $/HR	NORMAL BOILOFF =	400.0 GAL/DAY
MATERIALS =	500.00 $/YEAR	SHUTTLE LAUNCH =	530.5 GAL/LOADING
		DEWAR LOADING =	8548.0 GAL/LOADING
ESCALATION RATES,PERCENT/YEAR		TOTAL =	173293.2 LB/YEAR
OPERATING LABOR=	6.00	LIQ HYDROGEN COST=	1.75 $/LB
MAINTEN. LABOR =	6.00		
MAINTEN. MATL =	6.00	OPERATIONAL PARAMETERS	
POWER =	10.00	PERCENT DOWN TIME =	1.0%
LIQ NITROGEN =	10.00	NO. OF SHUTTLE LAUNCHES/YEAR=	16.0
WATER =	6.00	NO. OF DEWAR LOADINGS/YR =	16.0
LIQ. HYDROGEN =	0.		

------------------------ CASH FLOW ------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 575000.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 25197.4	$ 4805.6	$ 605003.0	$ 303263.0	$ -301740.0
2	$ 27507.5	$ 5093.9	$ 32601.4	$ 303263.0	$ 270661.6
3	$ 30036.0	$ 5399.6	$ 35435.5	$ 303263.0	$ 267827.5
4	$ 32804.0	$ 5723.5	$ 38527.5	$ 303263.0	$ 264735.5
5	$ 35834.7	$ 6067.0	$ 41901.6	$ 303263.0	$ 261361.4
6	$ 39153.4	$ 6431.0	$ 45584.4	$ 303263.0	$ 257678.6
7	$ 42768.2	$ 6816.8	$ 49605.0	$ 303263.0	$ 253658.0
8	$ 46769.6	$ 7225.8	$ 53995.5	$ 303263.0	$ 249267.5
9	$ 51131.3	$ 7659.4	$ 58790.7	$ 303263.0	$ 244472.3
10	$ 55910.3	$ 8119.0	$ 64029.3	$ 303263.0	$ 239233.8
11	$ 61147.1	$ 8606.1	$ 69753.2	$ 303263.0	$ 233509.8
12	$ 66886.4	$ 9122.5	$ 76008.8	$ 303263.0	$ 227254.2
13	$ 73177.0	$ 9669.8	$ 82846.8	$ 303263.0	$ 220416.2
14	$ 80072.8	$ 10250.0	$ 90322.8	$ 303263.0	$ 212940.2
15	$ 87632.9	$ 10865.0	$ 98497.9	$ 303263.0	$ 204765.1
	$ 756048.5	$ 111855.0	$ 1442903.5	$ 4548945.2	$ 3106041.7

PAY BACK OCCURS DURING YEAR 3
NET SAVINGS OVER 15 YEARS = 3.106 MILLION DOLLARS

-------------- IN 15 YEARS -------------------

TOTAL H2 SAVED WITH SYSTEM	=	2.599 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	=	5.387 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	=	.836 MILLION LBS
TOTAL NITROGEN EXPENDED	=	2.426 MILLION LBS
TOTAL WATER EXPENDED	=	12.476 MILLION GALS
TOTAL POWER EXPENDED	=	8.329 MILLION KW-HR

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OF POOR QUALITY

TABLE E-6. LIFE CYCLE COST, TWENTY LAUNCHES PER YEAR

TABLE ------ LIFE CYCLE COST ------SYSTEM 1 25% VENTING
TWO COMPRESSORS, 20 LAUNCHES, 12 HRS 15 YEAR LIFE

*CAPITAL INVESTMENT COST		OPERATING COST	
EQUIP AND MATL=	$ 295985.00	LABOR TIME=	8.0 HR/WEEK
DETAILED DESIGN=	$ 69929.00	LABOR RATE=	12.00 $/HR
FABRICATION =	$ 74255.00	POWER RATE=	.024 $/KW-HR
INSTALLATION =	$ 134831.00	LN2 RATE =	.041 $/LB
	-----------	WATER RATE=	.0003 $/GAL
TOTAL * (1.00)	$ 575000.00		

MAINTENANCE COST DATA
LABOR TIME= 6.9 HR/WEEK
LABOR RATE= 12.00 $/HR
MATERIALS = 500.00 $/YEAR

SAVINGS DATA
HYDROGEN RELIQUEFIED
NORMAL BOILOFF = 400.0 GAL/DAY
SHUTTLE LAUNCH = 530.5 GAL/LOADING
DEWAR LOADING = 8848.0 GAL/LOADING
TOTAL = 195360.4 LB/YEAR
LIQ HYDROGEN COST= 1.75 $/LB

ESCALATION RATES, PERCENT/YEAR
OPERATING LABOR= 6.00
MAINTEN. LABOR = 6.00
MAINTEN. MATL = 6.00
POWER = 10.00
LIQ NITROGEN = 10.00
WATER = 6.00
LIQ. HYDROGEN = 0.

OPERATIONAL PARAMETERS
PERCENT DOWN TIME = 1.0%
NO. OF SHUTTLE LAUNCHES/YEAR= 20.0
NO. OF DEWAR LOADINGS/YR = 20.0

------------------------ CASH FLOW --------------------------------

TOTAL CAPITAL INVESTMENT COST = $ 575000.00

YEAR	OPERATING COST	MAINTENANCE COST	TOTAL COST	GROSS SAVINGS	NET SAVINGS
1	$ 25970.0	$ 4805.6	$ 605775.6	$ 341880.7	$ -263894.9
2	$ 28356.6	$ 5093.9	$ 33450.5	$ 341880.7	$ 308430.1
3	$ 30969.3	$ 5399.6	$ 36368.9	$ 341880.7	$ 305511.8
4	$ 33629.9	$ 5723.5	$ 39553.4	$ 341880.7	$ 302327.2
5	$ 36962.4	$ 6067.0	$ 43029.3	$ 341880.7	$ 298851.4
6	$ 40393.0	$ 6431.0	$ 46824.0	$ 341880.7	$ 295056.7
7	$ 44150.9	$ 6816.8	$ 50967.7	$ 341880.7	$ 290913.0
8	$ 48267.6	$ 7225.8	$ 55493.4	$ 341880.7	$ 286387.3
9	$ 52778.0	$ 7659.4	$ 60437.4	$ 341880.7	$ 281443.2
10	$ 57720.6	$ 8119.0	$ 65839.5	$ 341880.7	$ 276041.1
11	$ 63137.3	$ 8606.1	$ 71743.4	$ 341880.7	$ 270137.3
12	$ 69074.3	$ 9122.5	$ 78196.8	$ 341880.7	$ 263683.9
13	$ 75582.4	$ 9669.8	$ 85252.3	$ 341880.7	$ 256628.4
14	$ 82717.4	$ 10250.0	$ 92967.4	$ 341880.7	$ 248913.2
15	$ 90540.5	$ 10865.0	$ 101405.5	$ 341880.7	$ 240475.1
	$ 780450.2	$ 111855.0	$ 1467305.2	$ 5128210.1	$ 3660905.0

PAY BACK OCCURS DURING YEAR 4
NET SAVINGS OVER 15 YEARS = 3.661 MILLION DOLLARS

-------------- IN 15 YEARS ------------------

TOTAL H2 SAVED WITH SYSTEM	= 2.930 MILLION LBS
TOTAL H2 LOST WITH NO SYSTEM	= 6.412 MILLION LBS
TOTAL H2 VENTED BY SYSTEM	= 1.045 MILLION LBS
TOTAL NITROGEN EXPENDED	= 2.369 MILLION LBS
TOTAL WATER EXPENDED	= 13.329 MILLION GALS
TOTAL POWER EXPENDED	= 8.898 MILLION KW-HR

VI. CYCLE ANALYSIS OF TEST CASES

Information from compressor manufacturers indicates that hydrogen reliquefaction system performance characteristics can be achieved with a four-stage compressor with suction pressure as low as 10 psia. Assuming a one psi line loss between the compressor and the condenser reservoir, the minimum operating pressure in the reservoir would be 11 psia. The thermal cycle analyzer computer program was run maintaining condenser reservoir pressure at 11 psia to determine any changes in operational characteristics or equipment sizing. Two test cases were run: the first with the system configuration as defined in the basic report, the second incorporating an ejector concept presently being developed by the National Bureau of Standards, Boulder, Colorado. This concept has the advantage of maintaining a low condenser pressure and above ambient pressure to the compressor, but additional components are required. A schematic comparison of the basic J-T valve system and the ejector system is presented in Figure E-4.

The analysis shows that the system operational characteristics and equipment size remain basically the same because the pressure and flow output from the compressor remains the same. Below ambient inlet pressure has some effect on compressor power consumption, but this would be insignificant in the opinion of compressor suppliers.

The incorporation of the ejector would require some packaging redesign of the cold box and would result in some enlargement of the base of the cold box. System safety would be improved and compressor operational parameters would be easier to achieve by operating at the above ambient pressure at the compressor inlet.

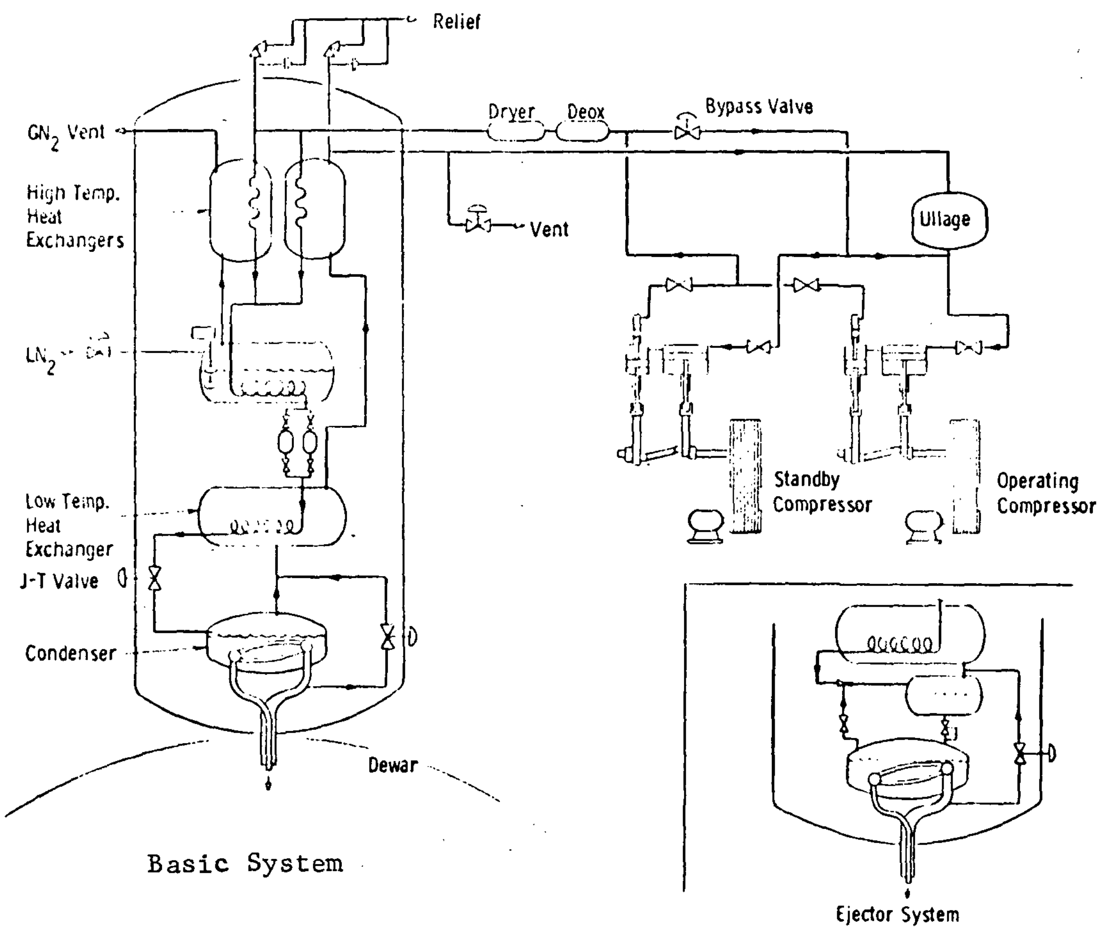
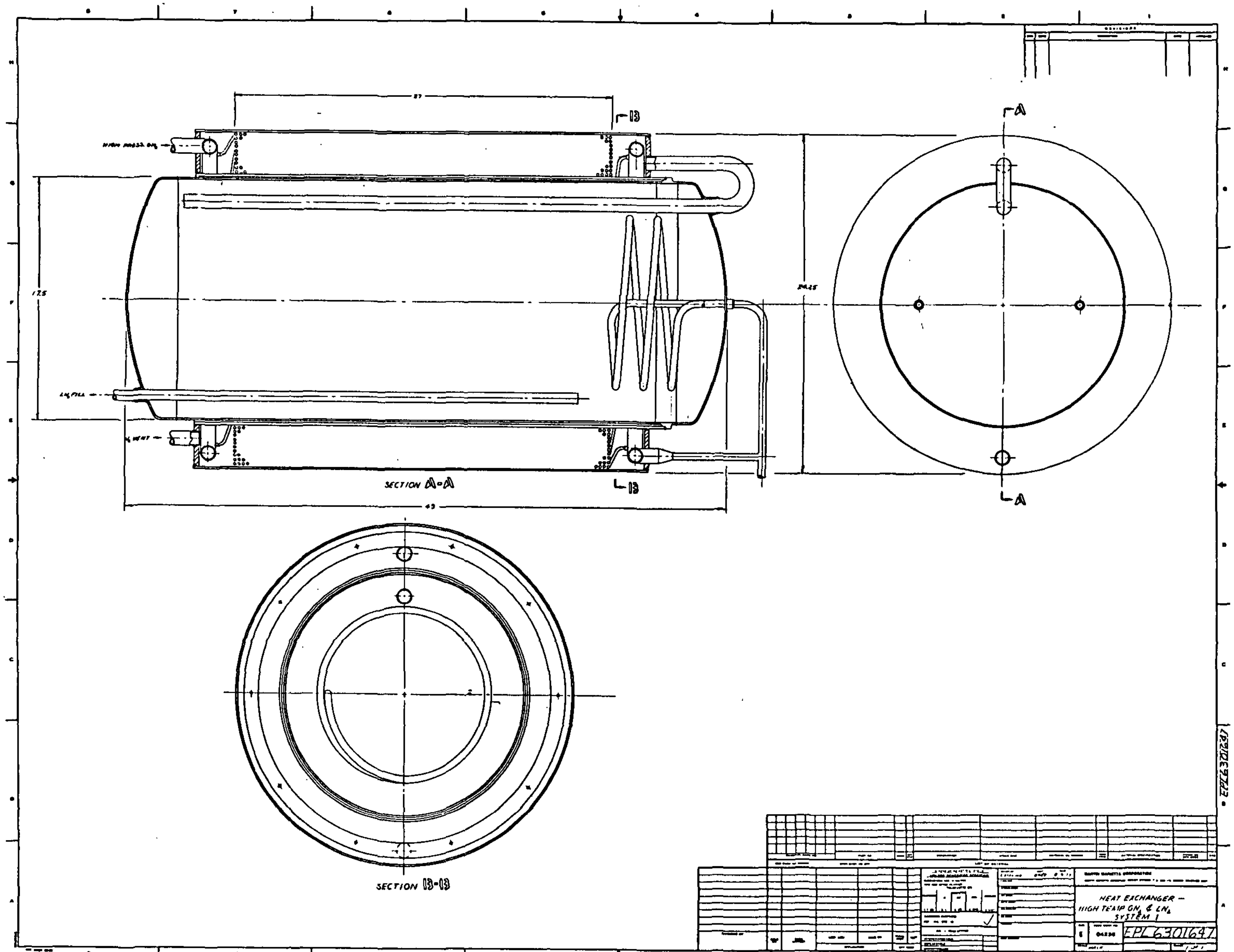


FIGURE E-4. COMPARISON OF BASIC HYDROGEN RELIQUEFACTION SYSTEM WITH J-T VALVE AND SYSTEM WITH EJECTOR

APPENDIX F
Conceptual Design Drawings for System Components and Cold Box



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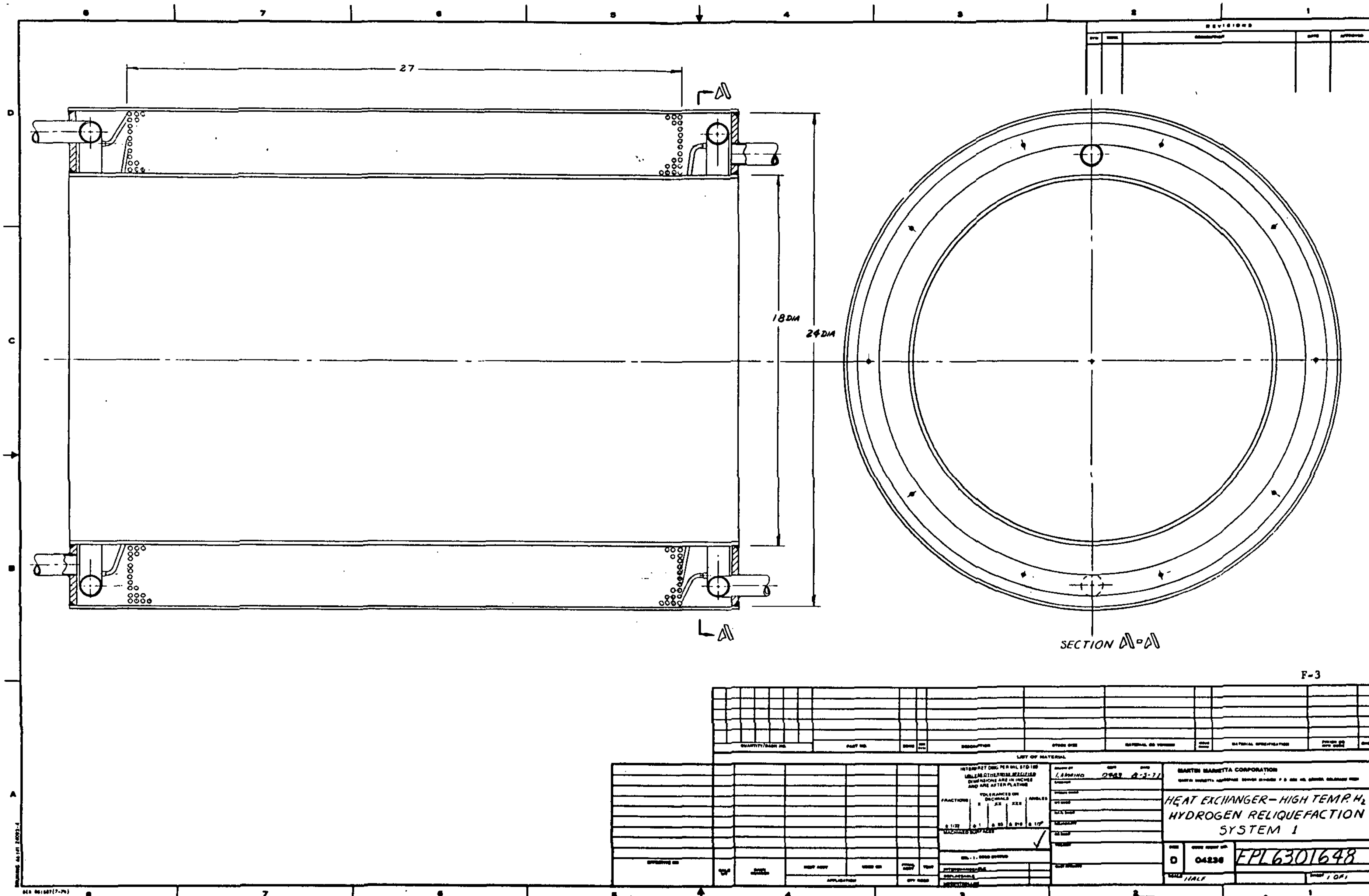
FOLDOUT FRAME 2



FOLDOUT FRAME 1

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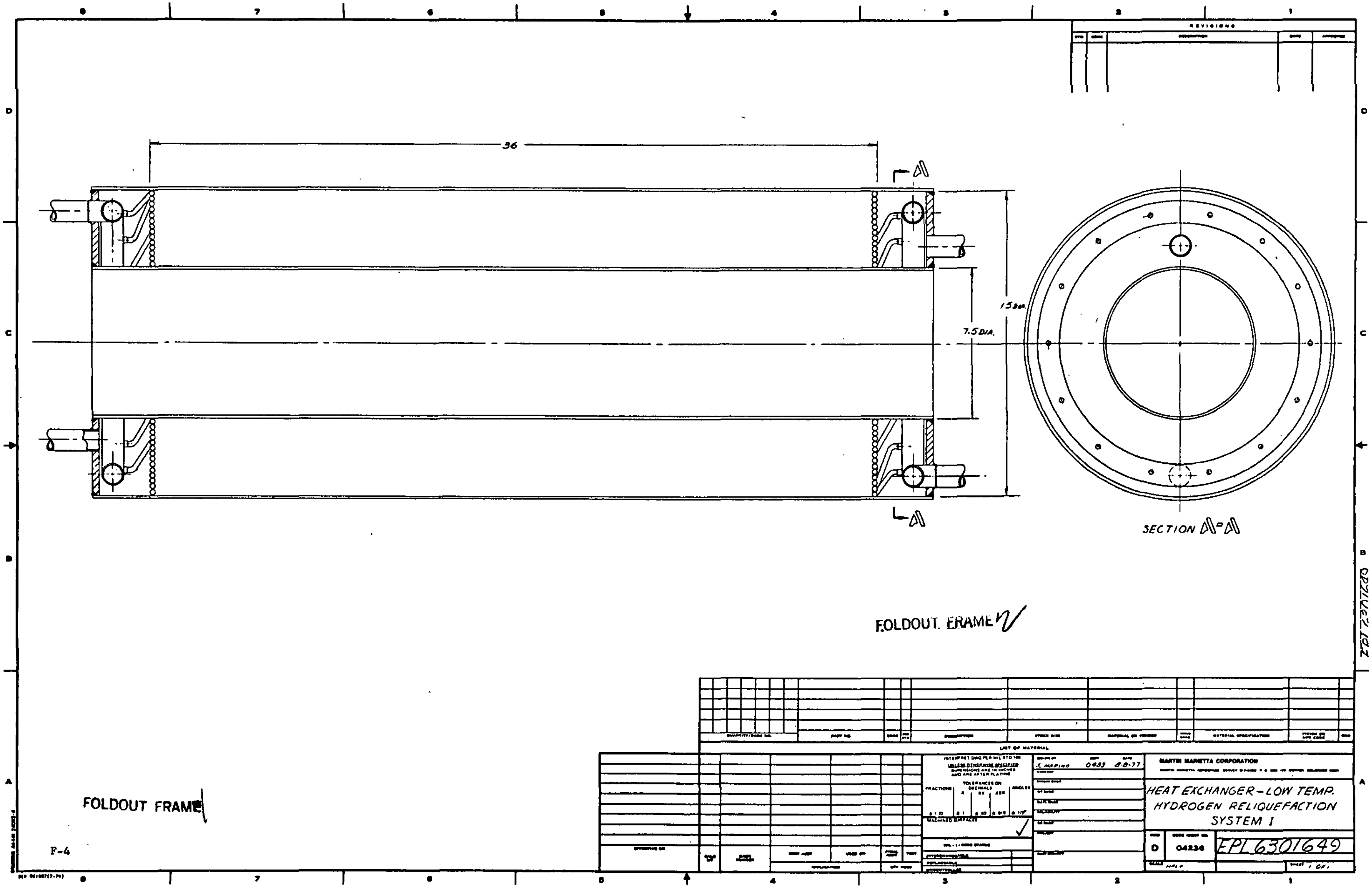

FOLDOUT FRAME

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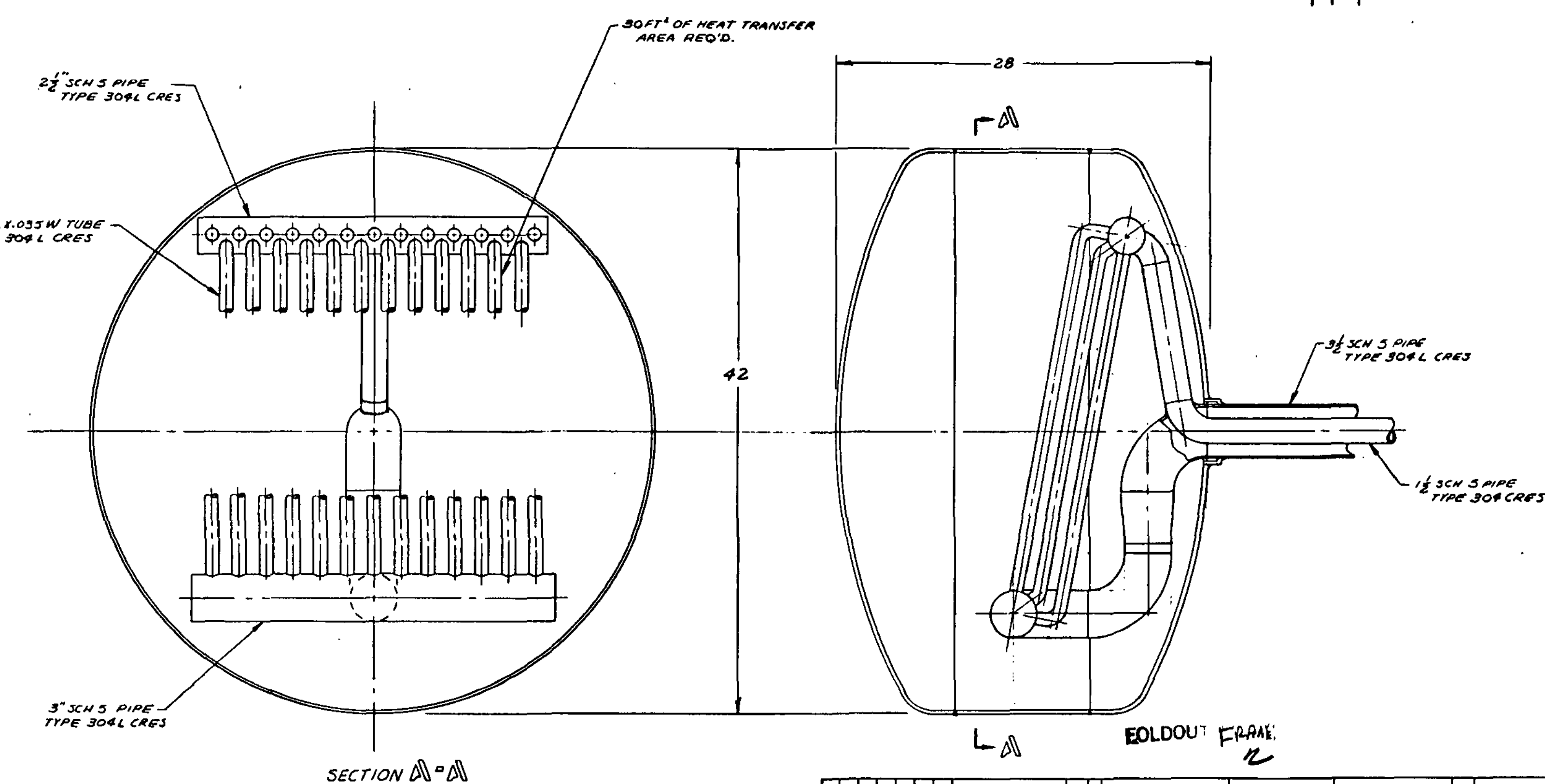
F-4



FOLDOUT FRAME 1

FOLDOUT FRAME 2

F-5

MARTIN MARIETTA CORPORATION

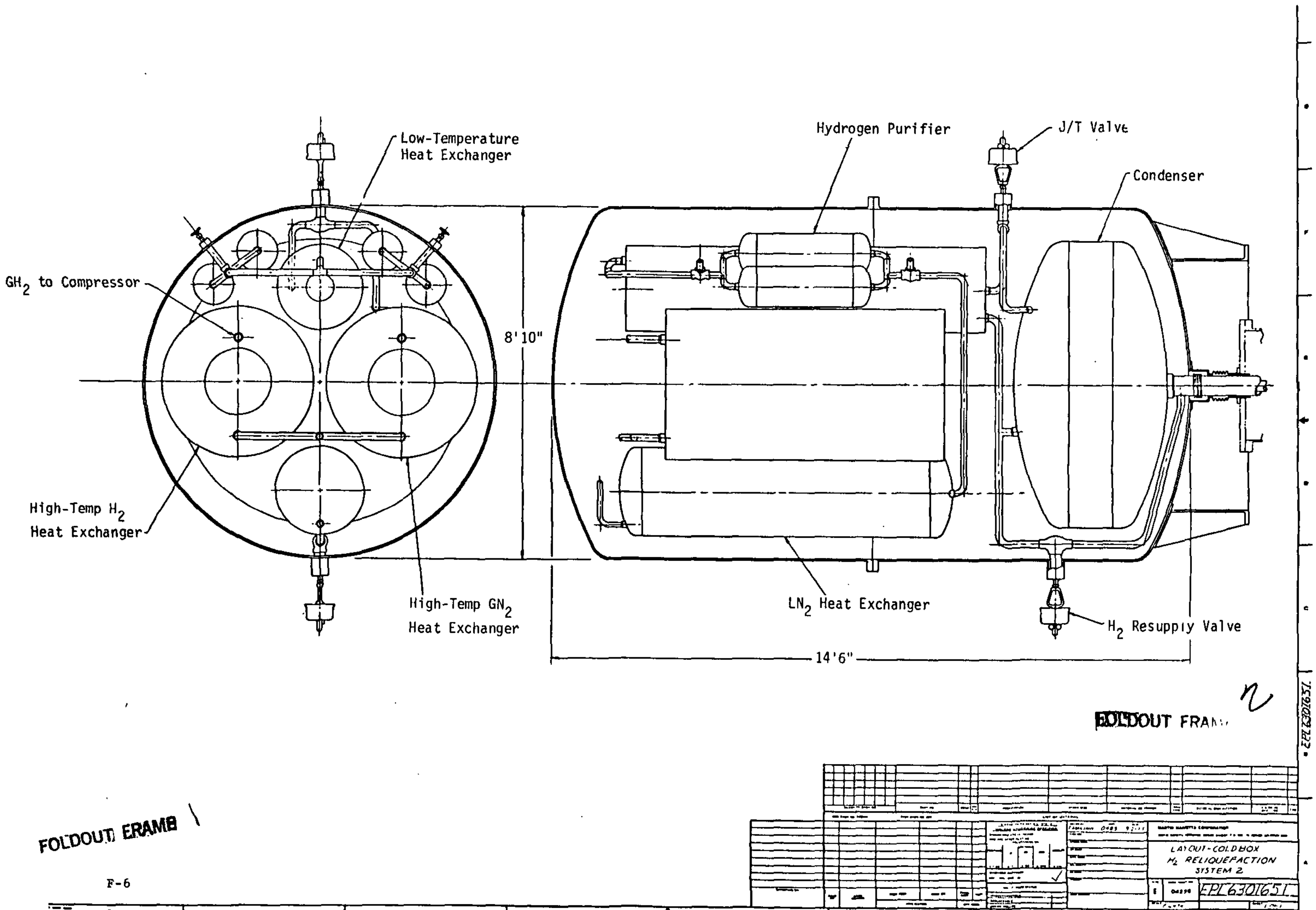
LAYOUT - LH_2 CONDENSER
HYDROGEN RELIQUEFACTION
SYSTEM 1

D 04236 EPL6301650

QUARTER

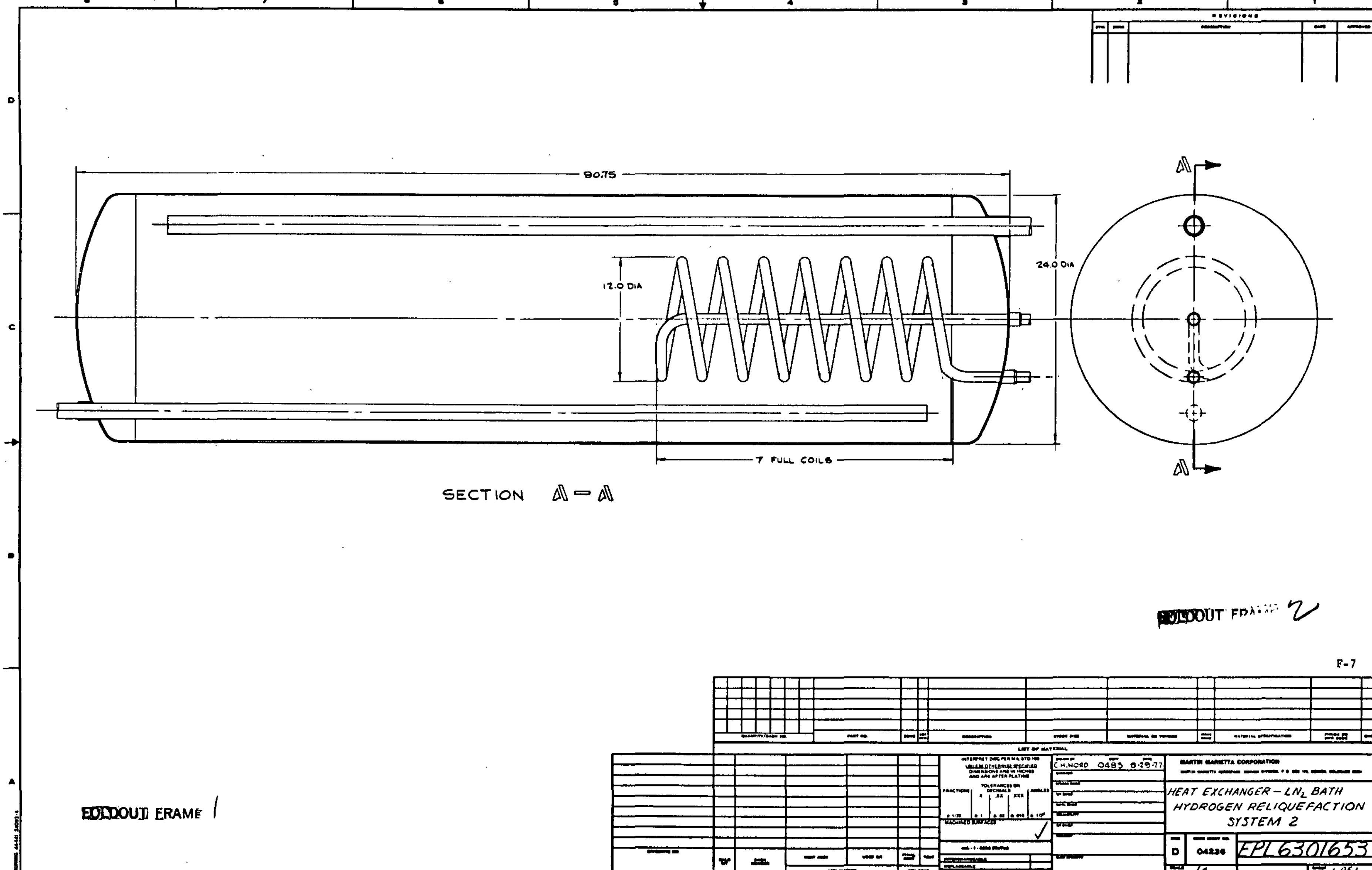
J. MARINO 0493 8-10-71

EPL6301650

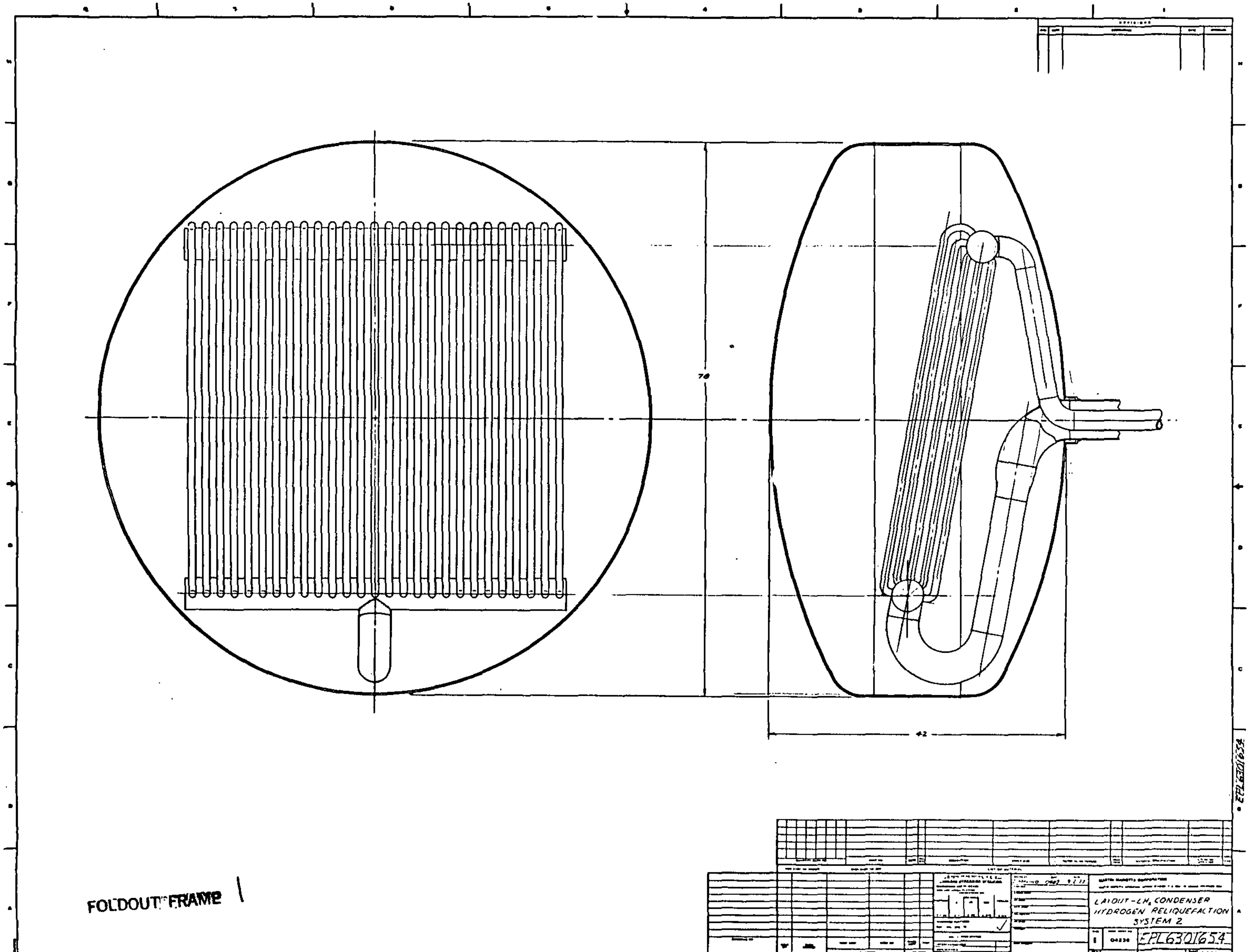


FOLDOUT FRAME 2

FOLDOUT FRAME 1



90.75
24.0 DIA
12.0 DIA
7 FULL COILS
SECTION A – A
FOLDOUT FRAME 1
FOLDOUT FRAME 2
F-7
EPL6301653
INTERPRET DWG PER MIL-STD-100
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING
C.H.NORD 0485 6-29-77
MARTIN MARIETTA CORPORATION
HEAT EXCHANGER – LN_2 BATH
HYDROGEN RELIQUEFACTION
SYSTEM 2
D 04236 EPL6301653
1/4
1 OF 1



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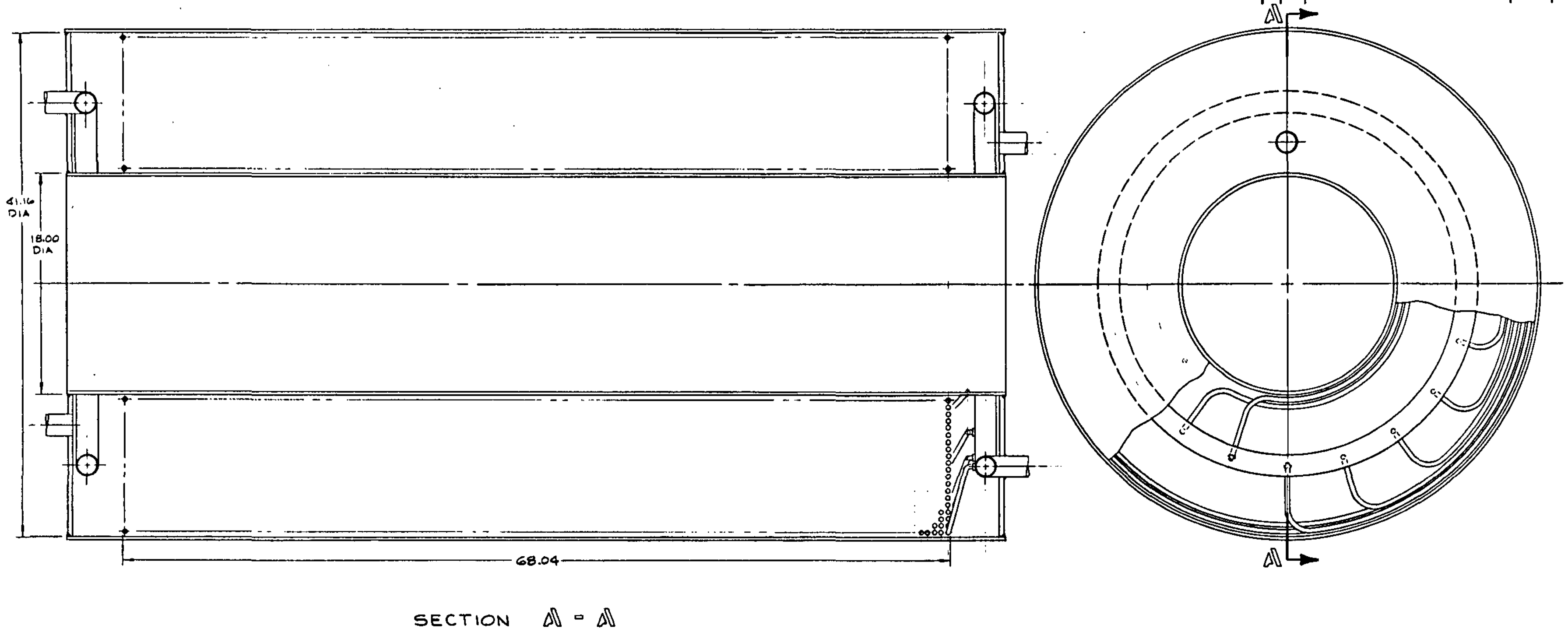
FOLDOUT FRAME 2

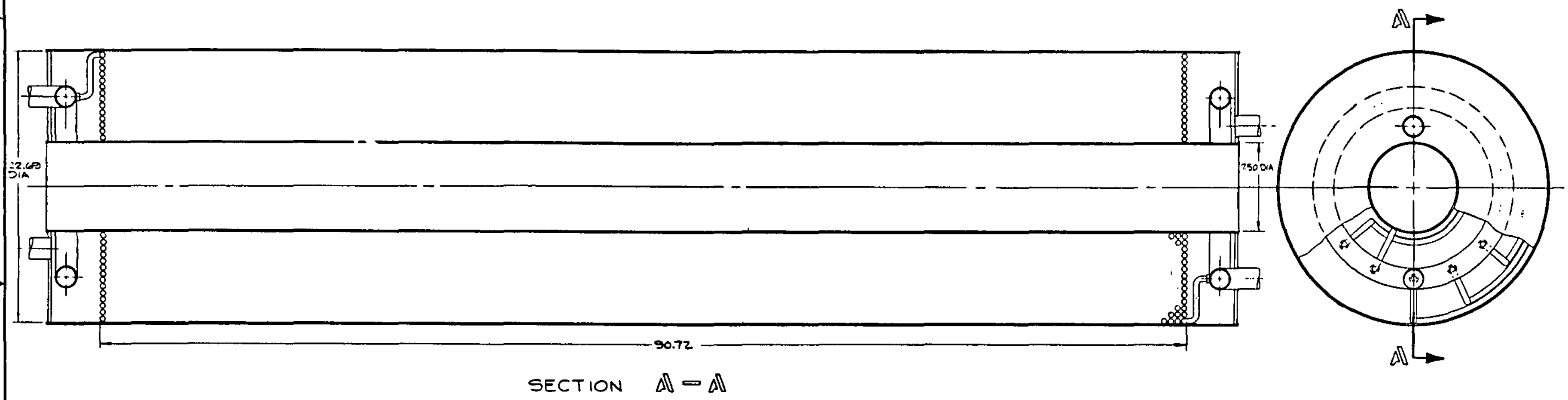


F-9

DRAWN BY	C.H.NORD 0483 8-26-77
	MARTIN MARIETTA CORPORATION
	HEAT EXCHANGER—HIGH TEMP HYDROGEN RELIQUEFACTION SYSTEM 2
SIZE	D
CODE IDENT NO.	04236
DRAWING NO.	EPL6301655
SCALE	1/4
SHEET	1 OF 1

EOLDOUT FRAME 1

EOLDOUT FRAME 2



MARTIN MARIETTA CORPORATION

HEAT EXCHANGER – LOW TEMP
HYDROGEN RELIQUEFACTION
SYSTEM 2

D 04236 EPL6301656

SCALE 1/4 SHEET 1 OF 1

F-10

FOLDOUT FRAME

APPENDIX G

Liquid Hydrogen Dewar Stress Analysis

Symbols Used in Stress Analysis

A	ASME Code shell geometry coefficient
A_f	Front area (ft^2)
A_S	Cross section area (in^2)
b	Stiffener spacing (inch)
B	ASME Code pressure coefficient
B_i	Shell extensional stiffness (lb/in)
C_D	Drag coefficient
D_i	Shell bending stiffness (lb-in)
E	Modulus of elasticity (lb/in^2)
E_e	Effective modulus of elasticity (lb/in^2)
ϵ_i	Shell strain (in/in)
F_{CCN}	Skin crippling allowable (lb/in^2)
F_D	Drag force (lb)
F_{tu}	Ultimate tensile strength (lb/in^2)
F_{ty}	Yield tensile strength (lb/in^2)
F_{cy}	Yield compressive strength (lb/in^2)
H	Height above ground (ft)
I_{ii}	Section moment of inertia (in^4)
ℓ_{CIR}	Length along circumference (in)
λ	Shell geometry parameter
MS_i	Section margin of safety
N_i	Shell membrane load (lb/in)
P_a	Shell external buckling pressure (lb/in^2)
P_{cr}	Critical normal load on shell (lb)
P_T	Cable tension load (lb)

R	Shell radius (inch)
ρ	Density of air ($lb\text{-}sec^2/ft^4$)
S	Shell stress intensity (lb/in^2)
S_M	ASME Code allowable stress intensity (lb/in^2)
$\sigma_{i_{CR}}$	Critical buckling stress i direction (lb/in^2)
σ_i'	Sum of pressure and mechanical stresses in i direction (lb/in^2)
σ_i	Shell stress (lb/in^2)
SD	Standard deviation
ϕ	Shell meridional direction
θ	Shell circumferential direction
t	Shell basic thickness (inch)
t_{SMEAR}	Smeared shell thickness (inch)
t_e	Effective shell thickness (inch)
V	Wind velocity (mph)
W_e	Effective skin width (inch)
$\bar{x}$	Section centroidal axis (inch)

1. SCOPE

This stress analysis was performed to determine the structural impact on the LH_2 sphere due to loading at the apex from a two compressor and four compressor reliquefaction unit.

2. DISCUSSION

The LH_2 sphere outer sphere requires strengthening for both configurations. A wind loading and blast pressure loading analysis was conducted for each configuration with the blast pressure of 2.0 psi being critical.

Since the original LH_2 sphere stress analysis was not available, it was necessary to determine the existing stress levels and critical buckling levels of the sphere without the apex loading. Several methods were investigated to envelop a range of buckling pressures. A critical apex load to produce buckling was then determined and a straight line interaction formula was used to combine the loading. A factor of safety of 1.5 was utilized in the load combinations.

The ASME code stress intensity requirements of paragraph AD 140 were also satisfied throughout the analysis. The code uses maximum shear theory failure and allows a maximum stress intensity of 16,700 psi when compared to the primary principal stresses at a given location.

3. Summary of LH_2 Dewar Modifications for Incorporation of a Two Compressor Hydrogen Reliquefaction Systems

1) Add 4 guy wire cables (1/4" dia - 1 x 10 stainless steel) pretensioned to 2770 pounds each. Locate so that blast pressure condition is 45° off of cables.

2) Add 11/16 plate x 6.00 inch high rolled frame to 68-inch dia.

3) Add 11/16 inch stiffness radially from manhole to new frame between every other bolt.

4) Add 11/16 plate stiffness radially from new frame 12 inches and taper to 2.00 inch at end.

5) It is desirable to make the modifications with spheres at ambient pressure.

4. Summary of LH_2 Dewar Modifications for Incorporation of a Four Compressor Hydrogen Reliquefaction System

1) For this preliminary analysis, the additional external stiffeness will be extended outward to the 9-7 internal frame. This is reasonable since only a finite element computer program can determine the actual stress distribution with the internal stiffner arrangement.

2) The external stiffness used in this analysis are W6x25 members rolled to the outer sphere 420-inch radius.

3) An additional 11/16 plate collar is carried from 23 to 44-inch radius. Plug welds should be included.

4) A rolled ring frame of 68 inch diameter is added over the new collar to interface with the cold box.

5) Six guy wires connected at points tangent to the dewar sphere are required for minimum preload (3/8" diameter 7x7 or 7x19 can be used). The cables should be loaded before installation to break in and pre-tensioned to 3,960 pounds at installation.

6) It is desirable but not mandatory that modifications be in corporated with the dewar at ambient pressure.

5. <u>Wind/Blast Over Pressure Loading Analysis for System 1</u>
The overall system dimensions are depicted in Figure G-1.
The following assumptions were made for this analysis:

- Assume 125 MPH max wind.
- Use 1.5 factor for vortex shedding and peak gusts.

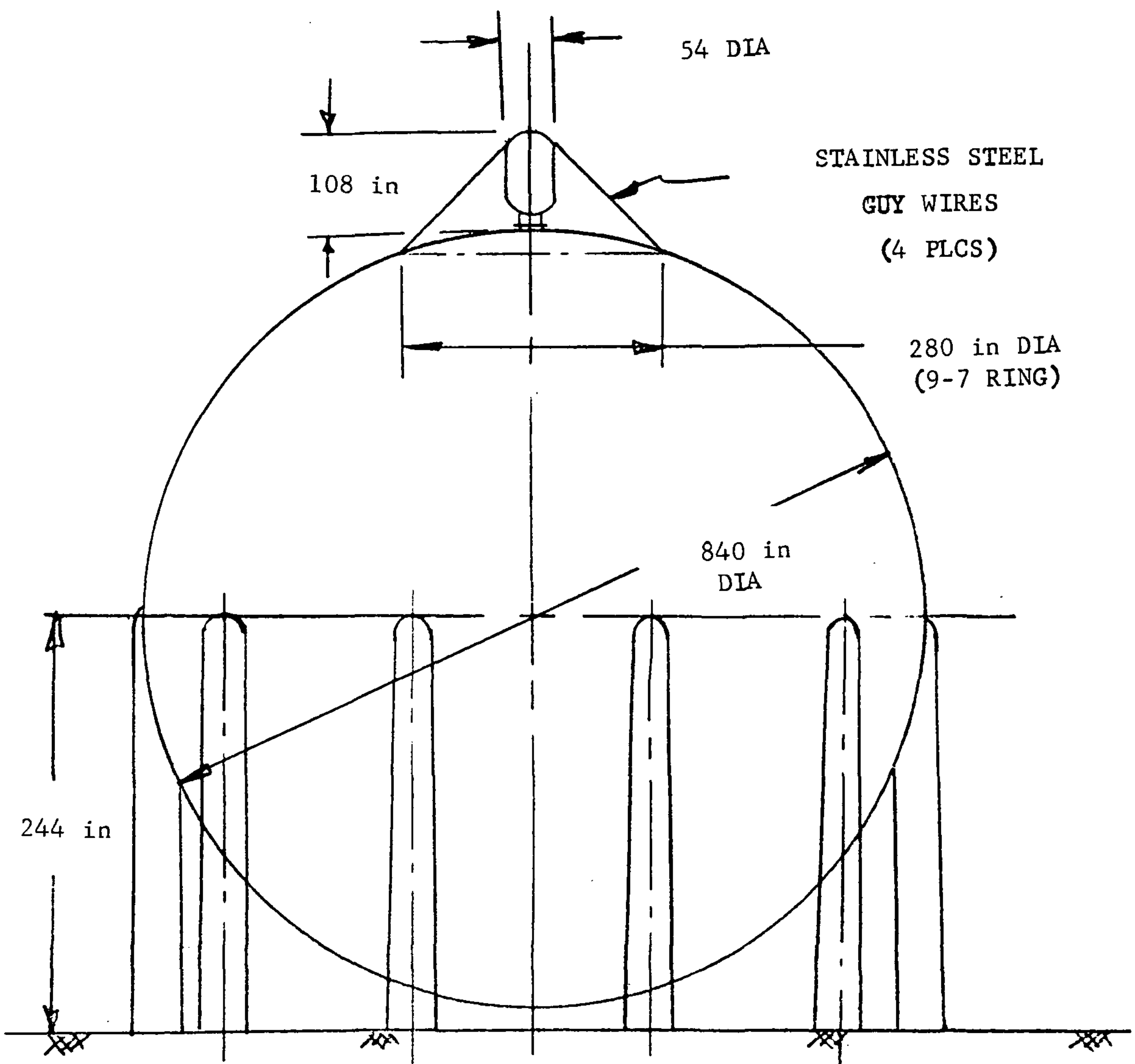


Figure G-1 Overall System Dimensions, System 1

- Assume 2.0 psig blast pressure on flat plate surface.
- Cold box weight: 6000 pounds.

Compute drag force (FD):

$$Fd = 1/2\ CD\ \rho A_f V^2$$

$$Cd = 0.8 \quad \text{(NASA SP8008 PG 4)}$$

$$A_f = \frac{54 \times 90}{144} = 33.75\ FT^2$$

$$V = 125\ MPH = 183.33\ FT/SEC$$

$$\rho = 0.00238\ \frac{LB\text{-}SEC^2}{FT^4}$$

$$Fd = \frac{0.8}{2}\ (0.00238)\ (33.75)\ (183.33)^2\ LB$$

$$Fd = 1079.9\ LBS$$

with 1.5 Vortex/Gust factor

$$Fd = 1{,}620\ LBS$$

As a check, use MMC method which considers height of structure above ground

$$Fd = 0.00256\ C_D V^2 \left[\frac{H}{30}\right]^{2/7} A$$

$$C_D = 0.8$$

$$V = 125\ MPH\ @\ 30\ FT\ \text{elevation}$$

$$H = 77.25\ FT\ @\ \text{center}$$

$$Fd = 0.00256\ (.8)\ (125)^2 \left[\frac{77.25}{30}\right]^{2/7} (33.75)\ LBS$$

$$Fd = 1415\ LBS$$

with 1.5 Vortex/Gust factor

$$Fd = 2123\ LBS$$

This analysis will use the Fd = 2123 LBS **value.** Stainless steel guy wires will be added to eliminate wind oscillation loads on the protruding unit. Four equally spaced guy wires will be considered, as depicted in Figure G-2.

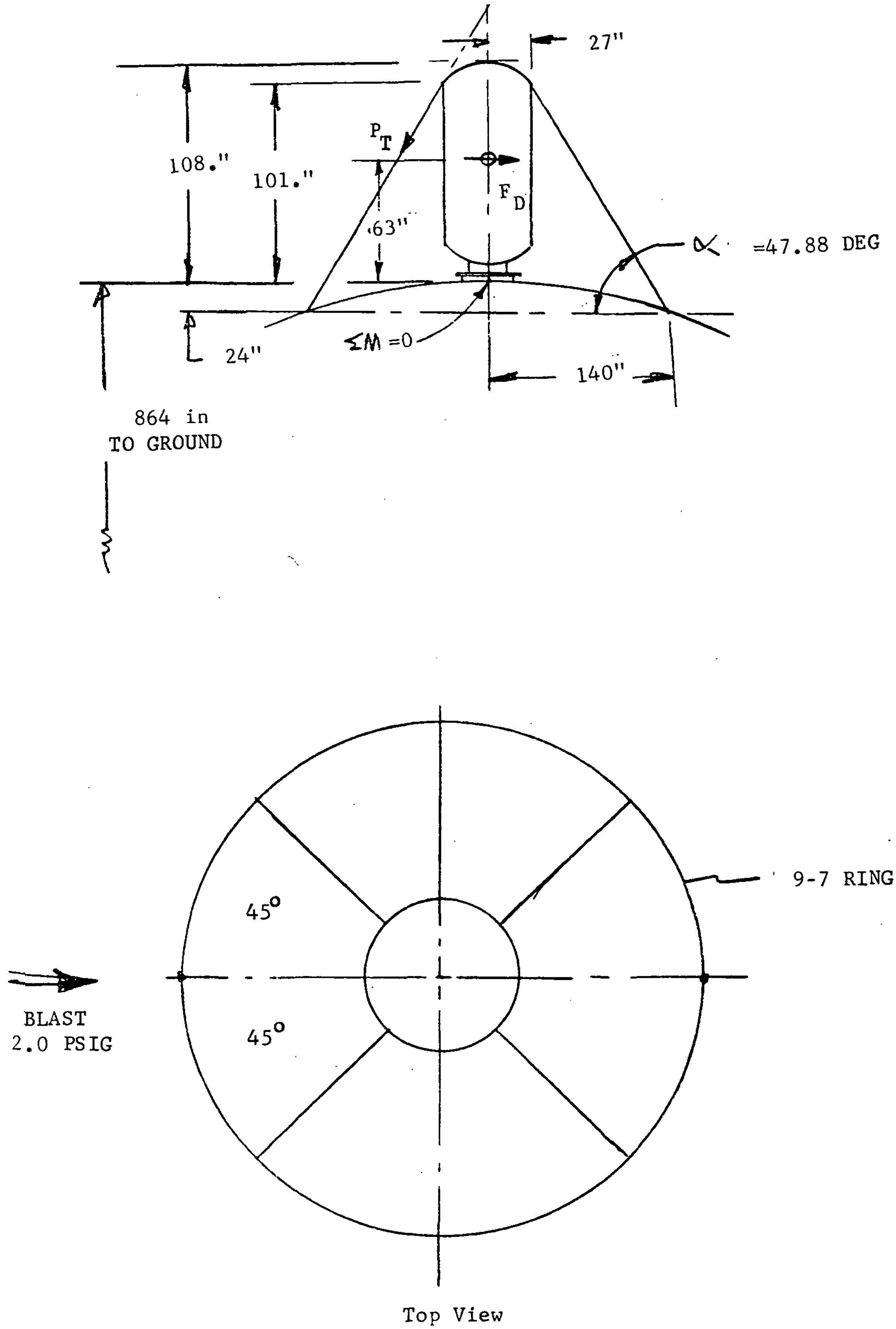


Figure G-2 - Guy Wire Configuration

The maximum load in a single guy wire (PT) is found by the moment summation at the nozzle/sphere intersection:

$$(Pt\cos 47.88)\,(140 \tan 47.88-24) = 2123\,(63)$$

$$Pt = \frac{2123(63)}{(\cos 47.88)\,(140 \tan 47.88-24)} \text{ LBS}$$

$$Pt = 1524.0 \text{ LBS}$$

Since the wind can come from any direction, this load is the maximum in a single guy wire with no load being reacted by the other three.

The 2.0 psig blast over pressure is a design goal. This pressure would be valid for a flat plate with side pressure. There will be less effective pressure than on a flat plate since the cylindrical shaped cold box will have a longer drag coefficient. From Hoerner's Book, Fluid-Dynamic Drag, a comparison of drag coefficients is made. (Hoerner, Fig. 7 Pg. 4-3).

$$Cd = 1.30 \text{ Plate}$$

$$Cd = .73 \text{ Cylinder}$$

Ratio down blast pressure for this analysis

$$\text{Press} = \frac{0.73}{1.30}\,(2.0) = 1.12 \text{ PSI}$$

The drag force from 125 MPH wind is equivalent to a side pressure of Press $= \dfrac{2123 \text{ LB}}{54\text{x}90 \text{ IN}^2} = 0.44$ psi

The resulting cable load from a 2.0 psig over pressure is calculated with the four guy wires spaced at 90 degree intervals and the direction of blast intersecting any two guy wires.

Two cables in tension with total horizontal reaction of

$$2(P_t' \cos\alpha) \cos 45^o$$

$$\Sigma M = 0$$

$$2(P_t' \cos 47.88)(\cos 45) \left[(140 \tan 47.88)-24\right] = 2(\frac{.73}{1.30}) (54\text{x}90)(63)$$

$$P_t' = \frac{2(\frac{.73}{1.30}) (54 \text{ x } 90) (63)}{2(\cos 47.88) (\cos 45) \left[(140 \tan 47.88 -24)\right]}$$

$$P_t = 2{,}771 \text{ LBS}$$

The total design load for concentrated vertical loading is then:

Unit dead weight	6,000 LBS
Pre-tensioned cables (4x2771 x sin 47.88)	8,220 LBS
Total	14,220 LBS

Required guy wire breaking strength is then:

$$\text{Min Break St.} = \frac{2771 \times 1.5}{.55} = 7{,}560 \text{ LBS}$$

(.55 factor for elastic limit)

Available size of stainless cord:

Dia	Strands	Breaking Strength
1/4	1 x 19	8,200 LBS

A minimum break-in loading of 10 cycles at 50% breaking strength should be applied before installation.

6. Dewar Stress Analysis for System 1

- ASME Section VIII - Division 2

Material Allowables SA285-C-FBX

Ftu = 55,000 PSI Min
Fty = 30,000 PSI

From Table ACS-1, the design stress intensity is
Sm = 16,700 PSI

- Determine the Shell Thickness Reqd without Stiffeners for a Full Vacuum (winter 1975 addenda, 12-31-75)

R = 420 In t = ?

Trial 1 Assume t = 1.25 In

$$A = \frac{.125}{R/t} = \frac{.125}{420/1.25} = 0.000375$$

Enter ACS -28.2 with A = 0.000372

Read: B = 5,400

Calculate allowable external working pressure

$$P_a = \frac{B}{R/t} = \frac{5400}{420/1.25} = 16.07 \text{ PSI}$$

This design thickness of 1.25 inch is adequate.

Calculate working stress in shell at 16.07 PSI external

$$\sigma = \frac{Pr}{2t} = \frac{(16.07)(420)}{(2)(1.25)} = 2{,}700 \text{ PSI}$$

It is noted that this is far below the allowable design stress intensity of 16,700 PSI, because the knockdown is necessary due to shell stability.

Using the corroded material allowance, the thickness utilized will be 0.625 inch. The allowable crippling stress of the shell along the stiffener using Fig. C 1.3.1 - 13 MSFC Stress Manual with 44 inch stiffener spacing:

$$\frac{b}{t}\sqrt{\frac{Fcy}{E}} = \frac{44}{.625}\sqrt{\frac{30{,}000}{29\text{x } 10^6}} = 2.26$$

$$Fccn = .72(30{,}000) = 21{,}600 \text{ PSI}$$

Using Fig. C 1.3.1 -12b and a working stress in the stiffener of 16,700 PSI

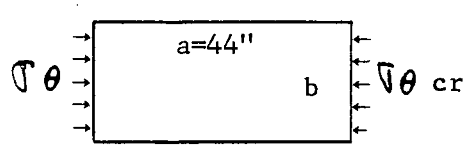
$$\frac{2We}{t} = 72$$

$$We = \frac{(.625)(72)}{2} = 22.5 \text{ inches}$$

In this analysis, the skin will be considered to be fully effective with the crippling allowable equal to 21,600 PSI along the stiffeners.

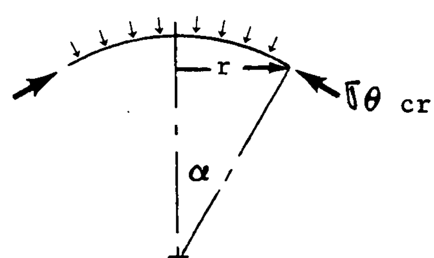
- Circumferential Buckling Stresses:

Plate with Edge Compression (1)



a	b	$\sigma\theta$ cr
44	22	27,000 PSI
44	44	21,600 PSI
44	66	11,340 PSI
44	88	9,396 PSI

Spherical Cap (2)



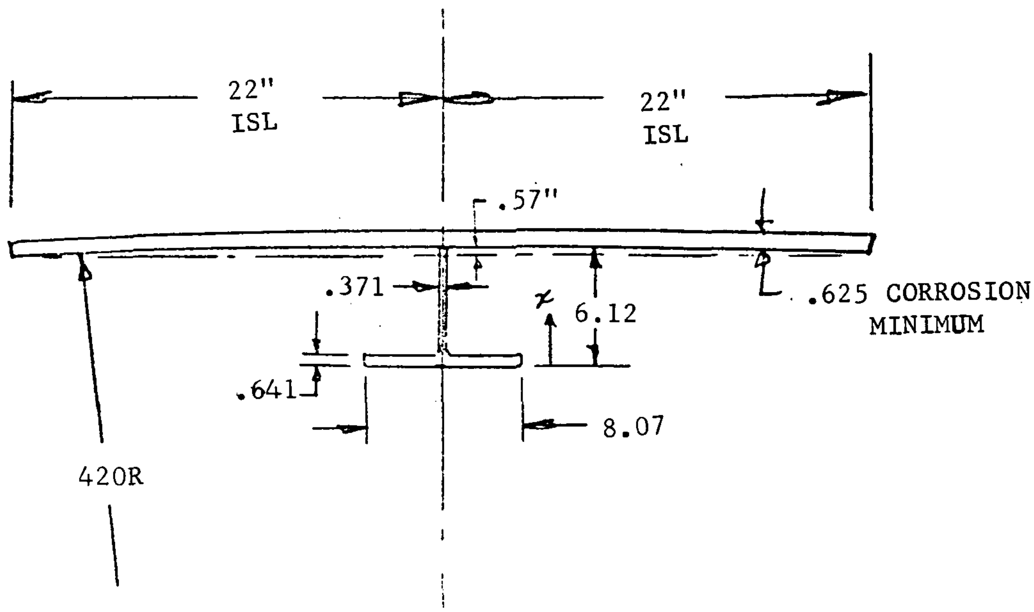
α	r(in)	$\sigma\theta$ cr
3^o	44	11,400 PSI
6^o	88	9,048 PSI

Conservatively use $\sigma\theta$ cr = 11,400 PSI for this analysis:

Analysis and design of Flight Vehicle Structure
(1) E. F. Bruhn 1965 Pg. C5.3-C5.5

(2) E. F. Bruhn Page C9.13 & C9.14.

- <u>Idealize Stiffened Skin Section Neglecting Local Cutouts</u>



* Assume flat plate

	Item	A	X	AX	AX^2	Io
*	Shell	27.5000	6.4325	176.89375	1137.869047	.895180
	Web	2.2705	3.060	6.94773	21.260053	7.086747
	Flange	4.9350	.3205	1.58166	0.5069244	.168976
		34.7055		185.42314	1159.636024	8.150903

$$\bar{X} = \frac{185.42314}{34.7055} = 5.34275 \text{ In}$$

$$I_{yy} = 8.150903 + 1159.636024 - 5.34275\ (185.42314)$$

$$I_{yy} = 177.1156 \text{ In}^4$$

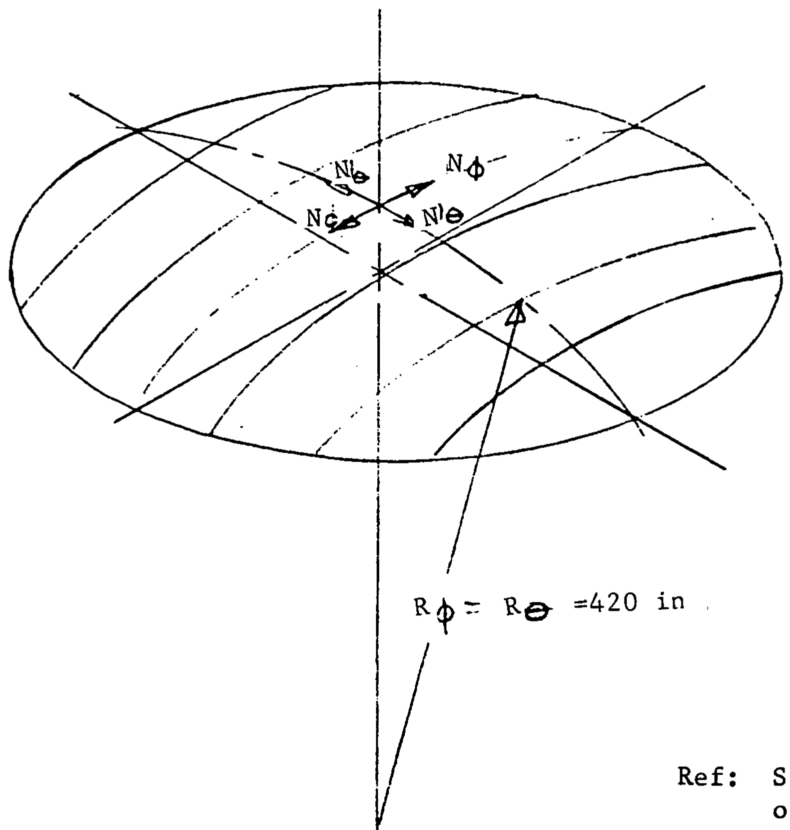
The membrane forces in the meridional (ϕ) and circumferential (θ) directions are equal to

$$N\phi = N\theta = \frac{Pr}{2} = \frac{(14.7)(420)}{2} = 3087.\ \text{LB/IN}$$

Due to the stiffeners, the extensional stiffness is different in the meridian and circumferential directions.

ϕ = Meridianal (stiffened) Direction

θ = Circumferential (unstiffened) Direction



Ref: Structural Analysis of shells, by Baker, Kovalevsky & Rish, McGraw-Hill 1972, Chp 7

Calculate the extensional stiffness in each direction:

$$\text{Meridional } B_\phi = \frac{EA}{1-\mu^2} = \frac{(29\times10^6)\left(\frac{34.7055}{44}\right)}{1-.32^2} \quad \frac{LB}{IN}$$

$$B_\phi = 25.4836 \times 10^6 \quad \frac{LB}{IN}$$

$$\text{Circumferential } B_\theta = \frac{(29\times10^6)(.625\times1)}{1-.32^2} \quad LB/IN$$

$$B_\theta = 20.19274\times10^6 \quad \frac{LB}{IN}$$

The strains in each direction can now be calculated:

$$(\text{merid}) \; \epsilon_\phi = \frac{N_\phi\,(1-\mu)}{B_\phi\,(1-\mu^2)} = \frac{(3087)\,(1-.32)}{(25.4836\times10^6)\,(1-.32^2)} \quad \frac{IN}{IN}$$

$$\epsilon\phi = 0.91770\times10^{-4} \text{ IN/IN}$$

$$(\text{circum})\ \epsilon\theta = \frac{(3087)(1-.32)}{(20.19274\times10^{6})(1-.32^{2})} \text{ IN/IN}$$

$$\epsilon\theta = 1.15815\times10^{-4} \text{ IN/IN}$$

Hookes Law can now be used to calculate the stresses in the basic shell.

Meridional $\sigma\phi = \frac{E}{1-\mu^2}(\epsilon\phi + \mu\epsilon\theta)$

$$\sigma\phi = \frac{29\times10^6}{1-.32^2}\left[.91770 + .32(1.15815)\right]10^{-4} \text{ PSI}$$

$$\sigma\phi = 4{,}162 \text{ PSI}$$

Circumferential $\sigma\theta = \frac{E}{1-\mu^2}(\epsilon\theta + \mu\epsilon\phi)$

$$\sigma\theta = \frac{29\times10^6}{1-.32^2}\left[1.15815 + .32\ (.91770)\right]10^{-4} \text{PSI}$$

$$\sigma\theta = 4{,}690 \text{ PSI}$$

These stresses are the best approximation that can be made with the available references and seem reasonable when compared with the unstiffened shell stress level of 4,940 PSI for 0.625 inch thick skin.

- Use method in Baker, Kovalevsky, Rish (EQ 7-6 Pg 185) to find equivalent isotropic section for simpler analysis:

  (1) Calculate stiffness parameters;

  a. Extensional stiffness:

  $$B = \frac{EA}{1-\mu^2} = \frac{(29\times10^6)\left[\frac{34.7055}{44}\right]}{1-.32^2} \text{ LB/IN}$$

  $$B = 25.4836\times10^6 \text{ LB/IN}$$

  b. Bending stiffness:

  $$D = \frac{EI}{1-\mu^2} = \frac{(29\times10^6)\ \frac{177.1156}{44}}{1-.32^2} \text{ LB-IN}$$

  $$D = 130.0526\times10^6 \text{ LB-IN}$$

(2) Calculate effective thickness:

$$t^e = \sqrt{\frac{12D}{B}} = \sqrt{\frac{12(130.0526)}{25.4836}} \quad \text{Inch}$$

$\underline{te = 7.8256 \text{ Inch}}$

(3) Calculate effective "E_e"

$$E_e = B\,(1-\mu^2)/t$$

$$E_e = \frac{25.4836\,(1-.32^2)}{7.8256} \times 10^6 = 2.9230 \times 10^6 \text{ LB/IN}^2$$

Using these equivalent values and ASME code curve ACS-28-2 Method, calculate critical buckling pressure:

$$A = \frac{.125}{R/t} = \frac{.125}{420/7.8256} = 0.00233$$

$$B = 15{,}500 \quad \text{(curve ACS 28.2)}$$

$$Pa = \frac{Bte}{R} = \frac{(15{,}500)(7.8256)}{420} \text{ LB/IN}^2$$

$$Pa = 288.80 \text{ LB/IN}^2$$

This pressure must be converted to a shell membrane load:

$$N\phi = N\theta = \frac{Pr}{2} = \frac{(288.8)\ (420)}{2} \frac{\text{LB}}{\text{IN}}$$

$$N\phi = N\theta = 60{,}650 \text{ LB/IN}$$

Calculate strains in equivalent shell

$$\epsilon\phi = \frac{(60{,}650)\ (1-.32)}{(25.483\times10^6)(1-.32^2)} = 1.803\times 10^{-3} \text{ IN/IN}$$

$$\epsilon\theta = \frac{(60{,}650)\ (1-.32)}{(20.193\times10^6)(1-.32^2)} = 2.275\times 10^{-3} \text{ IN/IN}$$

Finally, the stress levels in the shell are calculated:

Meridional $\sigma\phi = \frac{Ee}{1-\mu^2} \quad (\epsilon\theta + \mu\epsilon\theta)$

$$\sigma\phi = \frac{2.9224\times10^6}{1-.32^2}[1.803+.32(2.275)] \times 10^{-3} \frac{\text{LB}}{\text{IN}^2}$$

$$\underline{\underline{\sigma\phi = 8{,}240 \text{ LB/IN}^2}}$$

Circumferential

$$\sigma_\theta = \frac{Ee}{1-\mu^2}(\epsilon_\theta + \mu \epsilon_\phi)$$

$$\sigma_\theta = \frac{2.9224\text{x}10^6}{(1-.32^2)}\left[2.275 + .32(1.803)\right] \text{ x } 10^{-3} \frac{LB}{IN^2}$$

$$\underline{\sigma_\theta = 9{,}285 \quad LB/IN^2}$$

Now, to complete the solution, the external pressure (Pa) necessary to develope these stress levels in the origional shell must be determined.

The meridional stress is given as;

$$\sigma_\phi = \frac{E}{1-\mu^2}(\epsilon_\phi + \mu \epsilon_\theta)$$

Where: $\sigma_\phi = 8{,}240$ PSI

$$\epsilon_\phi = \frac{PaR}{2B_\phi}\frac{(1-\mu)}{(1-\mu^2)} = \frac{Pa(420)(1-.32)}{2(25.4836\text{x}10^6)(1-.32^2)} \quad IN/IN$$

$$\epsilon_\phi = Pa(6.2428\text{x}10^{-6}) \quad IN/IN$$

$$\epsilon_\theta = \frac{PaR}{2B_\theta}\frac{(1-\mu)}{(1-\mu^2)} = \frac{Pa(420)(1-.32)}{(2)(20.193\text{x}10^6)(1-.32^2)} \quad IN/IN$$

$$\epsilon_\theta = Pa(7.8785\text{x}10^{-6}) \quad IN/IN$$

Substitution then gives

$$8{,}240 = \frac{29\text{x}10^6 Pa}{(1-.32^2)}\left[6.2428 + .32(7.8785)\right] \text{x}10^{-6}$$

$$Pa = \frac{(8{,}240)(1-.32^2)}{(29)(8.7639)} \quad LB/IN^2$$

$$Pa = 29.10 \; LB/IN^2$$ ASME code using Fig. ACS-28-2

Equations are presented for calculating external buckling pressures on spherical caps based on General Dynamics report AS-D-568. (Ref: Analysis & Design of Flight Vehicle Structures E. Bruhn Pg. C9.13 P C9.14).

Mean expected $Pa = \frac{.3122\ Et^2}{R^2(\sin\alpha)1/3}$ LB/IN^2

90% Probability
& .95 Confidence $Pa = \frac{.2276\ Et^2}{R^2(\sin\alpha)\ 1/3}$ LB/IN^2

99% Probability
& .95 Confidence $Pa = \frac{.1816\ Et^2}{R^2(\sin\alpha)\ 1/3}$ LB/IN^2

Using the equivalent thickness and elasticity values

$te = 7.8256$ In $Ee = 2.923\times10^6$ LB/IN^2

Pam = 456.69 PSI

Pa90% = 332.94 PSI

Pa99% = 265.65 PSI

Using the previous method, the equivalent pressures can be converted to collapse pressures in the stiffened shell:

Mean Pa = 46.0 LB/IN^2

90% Probability Pa = 33.5 LB/IN^2

99% Probability Pa = 26.8 LB/IN^2

With the above data, the standard deviation (SD) is determined:

$$SD_{90} = \frac{46.0-33.5}{1.645} = 7.60\ \text{LB/IN}^2$$

$$SD_{99} = \frac{46.0-26.8}{2.575} = 7.46\ \text{LB/IN}^2$$

Using average SD= 7.53 PSI, calculate 97.5% probability (2.24 Sigma)

$$Pa_{97.5\%} = 46.0 - 7.53(2.24)\ \text{LB/IN}^2$$

$$Pa_{97.5\%} = 29.13\ \text{LB/IN}^2$$

This is in good agreement with ASME code.

Determine critical buckling load on cap use Baker, Kovalevsky & Rish, Structural Analysis of Shells, Pg. 255:

$$Pcr = \frac{\lambda^2\ Et^3}{24\ R} \qquad 4 \leq \lambda \leq 18$$

Using .625 unstiffened shell

$$\lambda = \left[12(1-.32^2)\right]^{\frac{1}{4}} \left[\frac{420}{.625}\right]^{\frac{1}{2}} 2 \quad \sin \frac{19.5}{2}$$

$$\lambda = 15.91$$

$$Pcr = \frac{(15.91)^2(29x10^6)(.625)^3}{24\ (420)} \quad LBS$$

$$Pcr = 177{,}708 \quad LBS$$

Stress levels in skin are calculated around manhole collar (23.0 inch radius)

$$\phi = \sin^{-1}\frac{23}{420} = 3.139 \text{ deg}$$

$$\sigma\phi = \frac{Pcr}{2\pi\ Rt\sin^2\phi} = \frac{177{,}708}{2\pi\, 420(.625)\ \ \sin^2 3.139} \quad LB/IN^2$$

$$\sigma\phi = 35{,}921 \quad PSI$$

$$\sigma\theta = \frac{Pcr}{2Rt\sin^2\phi} = \frac{177{,}708}{2(420)(.625)\ \ (\sin^2 3.139)} \quad LB/IN^2$$

$$\sigma\theta = 112{,}850 \quad LB/IN^2$$

This is much to high so the critical concentrated load must be reduced so that skin bucklingwill not be present in the critical circumferential direction with $\sigma\theta cr = 11{,}400$ PSI @ 23 inch radius.

$$N\phi = \frac{Pcr}{2(420\pi)\ \sin^2 3.139} = 0.126377\ Pcr \quad LB/IN$$

$$N\theta = \frac{Pcr}{2(420)\ \sin^2 3.139} = 0.397025\ Pcr \quad LB/IN$$

$$\epsilon\phi = \frac{[.126377-.32(.397025)]\ Pcr}{25.4836x10^{-6}\ (1-.32)^2} = -2.9334x\ 10^{-11}\ Pcr$$

$$\epsilon\theta = \frac{[.397025-.32(.126377)]\ Pcr}{(20.193x10^6)(1-.32^2)} = 1.96733x\ 10^{-8}\ Pcr$$

$$\sigma\theta = \frac{E}{1-\mu^2}(\epsilon\theta + \mu\epsilon\phi)$$

$$11{,}400 = \frac{29x10^6}{1-.32^2}\left[1.96733x10^{-8}+.32(-2.9334x10^{-11})\right] Pcr$$

$Pcr = 17{,}943$ LBS (Load necessary for circumferential buckling without external shell pressure)

C-4

- A straight line interaction formula is recommended by Baker, Kovalevsky and Rish for spherical caps and spheres under combined external pressure and concentrated load:

$$\frac{P}{P_{cr}} + \frac{P}{P_{cr}} \leq 1.0$$

Where:

P = applied external pressure or resulting stress

P_{cr} = Critical external buckling pressure or resulting stress

P = Applied concentrated load or resulting stress

P_{cr} = Critical concentrated load producing buckling or resulting stress

For this design use factor of safety of 1.5 on buckling.

From 14.7 PSI external pressure $\sigma_{\phi} = 4{,}162 \text{ LB/IN}^2$

$\sigma_{\theta} = 4{,}690 \text{ LB/IN}^2$

From 29.1 PSI external pressure (buckling)

$\sigma_{\phi_{cr}} = 8{,}240 \text{ LB/IN}^2$

$\sigma_{\theta_{cr}} = 9{,}285 \text{ LB/IN}^2$

The interaction equation then becomes:

$$\frac{14.7\ (1.5)}{29.1} + \frac{14{,}220\ (1.5)}{17{,}943} = .758 + 1.188 > 1.0$$

Since this condition is not satisfied, the area requires additional stiffening for the stability analysis.

Check to see if the allowable stress intensity of 16,700 PSI per ASME code AD-140 is satisfied.

Calculate stresses in the shell at 23-inch radius from the 14,220 pound concentrated load.

$$N\phi = \frac{14{,}220}{2\pi\ (420)\text{Sin}^2 3.139} = 1797.0 \text{ LB/IN}$$

$$N\theta = \frac{14{,}220}{2\ (420)\ \text{Sin}^2 3.139} = 5{,}646.0 \text{ LB/IN}$$

$$\epsilon_\phi = \frac{(1797-.32(5646))}{25.4836x10^6(1-.32^2} = -4.2494 \times 10^{-7}$$

$$\epsilon_\theta = \frac{(5646-.32(1797)}{(20.193x10^6)(1-.32^2)} = 27.9773x10^{-5} \text{ IN/IN}$$

$$\sigma_\phi = \frac{29x10^6}{1-.32^2} (-0.042494 + .32\ (27.9773))x10^{-5} \text{ LB/IN}^2$$

$$\sigma_\phi = 2{,}880 \text{ LB/IN}^2$$

$$\sigma_\theta = \frac{29x10^6}{1-.32^2}(27.9773 + .32(-.042494))x10^{-5} \text{ LB/IN}^2$$

$$\sigma_\theta = 9{,}035 \text{ LB/IN}^2$$

The combined stresses are:

$$\sigma_\phi' = -4{,}162 - 2{,}880 = -7{,}042 \text{ LB/IN}^2$$

$$\sigma_\phi' = -4{,}690 - 9{,}035 = -13{,}725 \text{ LB/IN}^2$$

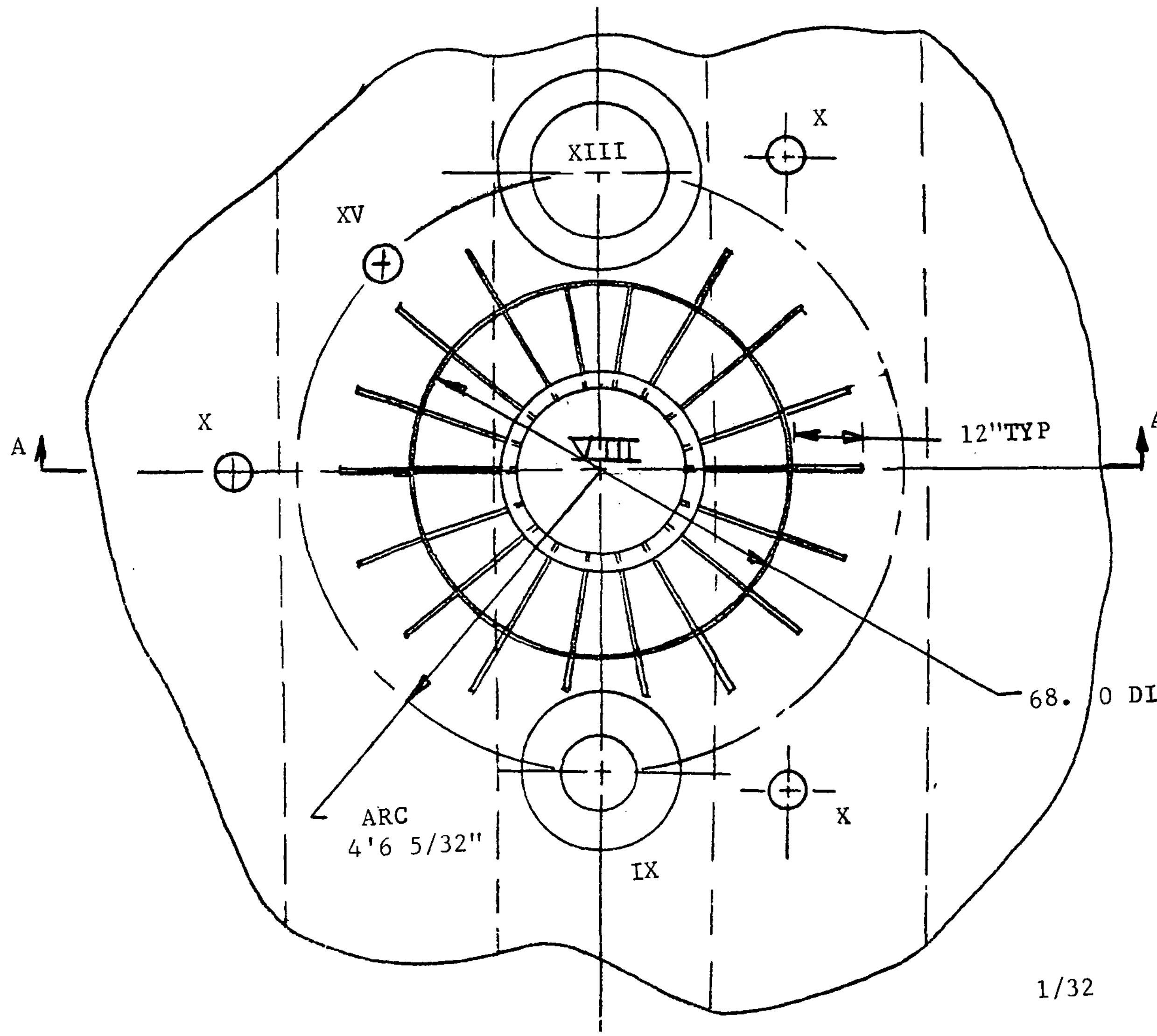
The stress intensity is:

$$S = -13{,}725 - (-7{,}042) = -6{,}683 \text{ LB/IN}^2$$

This satisfies ASME code AD-140.

Evaluate stiffened shell configuration depicted in Figure G-3. The stiffeners include a circumferential ring and meridional stiffeners between every other manhole bolt or on 20 degree spacing. The radial stiffeners extend from the new ring outboard 12 inches and taper down to an end thickness of two inches.

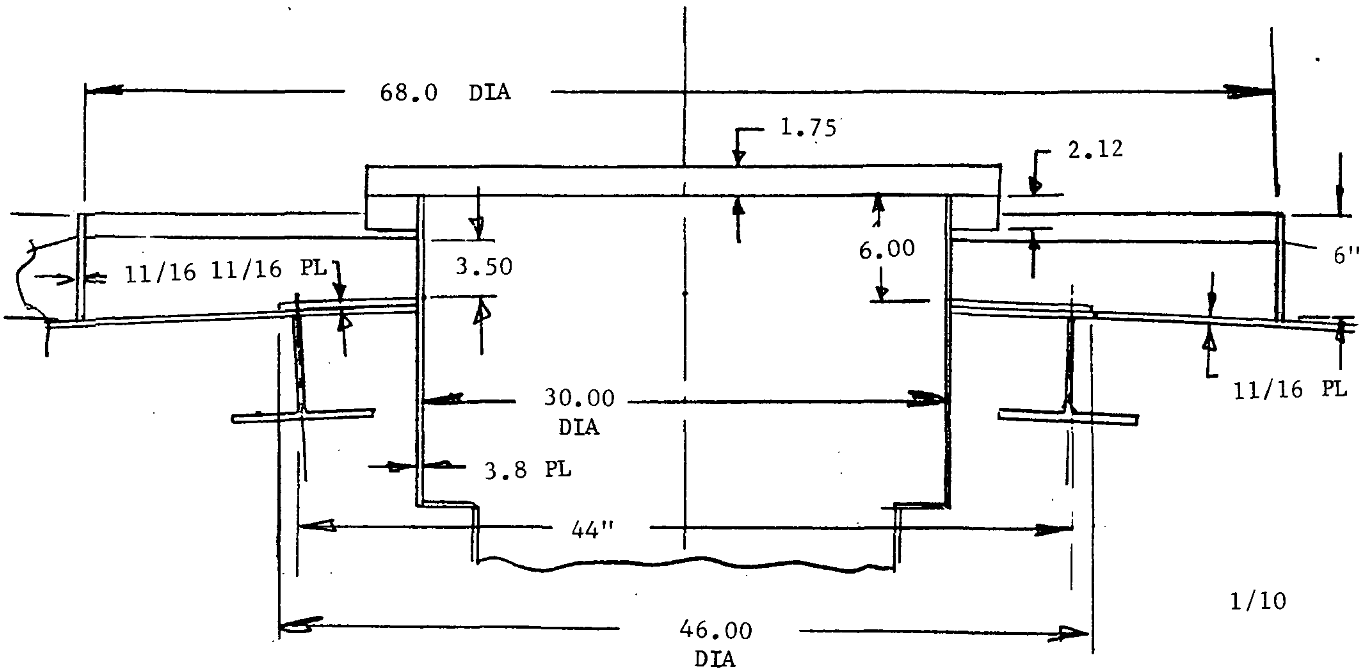
(See Page G-22)



Mark	DIA
VIII	30.0
IX	12.0
X	4.0
XIII	24.0

Use 11/16 plate for new structure with 1/16 corrosion allowable.

Figure G-3. Plan View - Sphere Top with Stiffeners



SECTION A-A - Shell Stiffener

Check stress intensity at edge of manhole collar (R = 23. inches)

Rib spacing with 20 deg stiffness:

$$b = \frac{20}{360} \pi (46) = 8.02 \text{ inch}$$

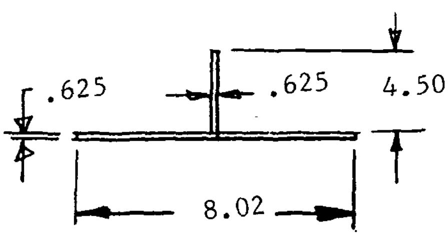
Half angle on sphere with 23" radius

$$\phi = \sin^{-1} \frac{23}{420} = 3.139 \text{ deg}$$

For circumferential stiffness use effective skin thickness of .625 inch:

$$B_\theta = \frac{29 \times 10^6 (.625)}{1 - .32^2} = 20.193 \times 10^6 \text{ LB/IN}$$

Meridional Stiffness:



$$A_s = .625\ (4.5 + 8.02) \text{ in}^2$$

$$A_s = 7.825 \text{ in}^2$$

$$t_{smear} = \frac{A_s}{8.02} = \frac{7.825}{8.02} = 0.975 \text{ in}$$

$$B_\phi = \frac{(29 \times 10^6)\ (.975)}{1 - .32^2} = 31.500 \times 10^6 \text{ LB/IN}$$

Using stiffened section properties, evaluate membrane loads and stresses at 23.0 inch radius due to 14,220 LB load on manhole:

$$\sin \phi = \frac{23}{420} = 0.05476$$

$$N \phi = \frac{14,220}{2(420)\ \pi\ (0.05476)^2} = 1797 \text{ LB/IN}$$

$$N_\Theta = \frac{14,220}{2(420)(0.05476)^2} = 5,645. \text{ LB/IN}$$

$$\epsilon_\phi = \frac{1797-.32(5645)}{(31.5 \times 10^6)(1-.32^2)} = -3.3245 \times 10^{-7} \text{ IN/IN}$$

$$\epsilon_\Theta = \frac{5645-.32(1797)}{(20.193 \times 10^6)(1-.32^2)} = 27.9718 \times 10^{-5} \text{ IN/IN}$$

$$\sigma_\phi = \frac{(29 \times 10^6)(-3.3254 \times 10^{-7} + .32(27.9718 \times 10^{-5}))}{1-.32^2} \text{ LB/IN}^2$$

$$\sigma_\phi = 2,880 \text{ LB/IN}^2$$

$$\sigma_\Theta = \frac{(29 \times 10^6)(27.9718 \times 10^{-5} + .32(-3.3254 \times 10^{-7}))}{1-.32^2} \frac{\text{LB}}{\text{IN}^2}$$

$$\sigma_\Theta = 9,034 \text{ LB/IN}^2$$

Combined stresses from pressure and concentrated loading:

$$\sigma_\phi' = \sigma_{\phi p} + \sigma_{\phi c} = -4,162 - 2880 \text{ LB/IN}^2$$

$$\sigma_\phi' = -7,042 \text{ LB/IN}^2$$

$$\sigma_\Theta' = \sigma_{\Theta p} + \sigma_{\Theta c} = -4,690-9034 \text{ LB/IN}^2$$

$$\sigma_\Theta' = -13,724 \text{ LB/IN}^2$$

The stress intensity is then:

$$S = -13,724-(-7,042) = -6,682 \text{ LB/IN}^2$$

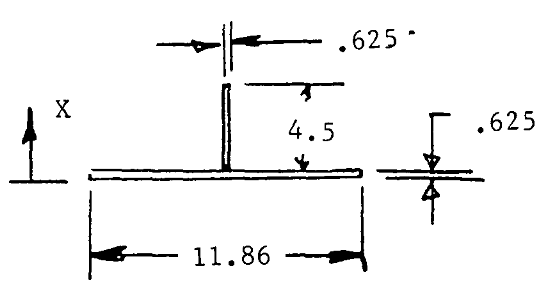
Since this is less than 16,700 psi, ASME code paragraph AD 140 is satisfied.

Check margin of safety for crippling and the circumferential direction with $\sigma_{\theta cr}$ = 27,000 PSI:

$$MS_{\theta} = \frac{27{,}000}{(1.5)(13{,}724)} - 1$$

$$\boxed{MS_{\theta} = +0.312}$$ circumferential @ 23.0 inch radius

Meridional stiffness at 68 in DIA:



$$\bar{X} = \frac{10.2799}{9.833} = 1.091 \text{ IN}$$

$$Iy = 4.9746 + 23.9326 - 1.091\,(10.2799) \text{ IN}^4$$

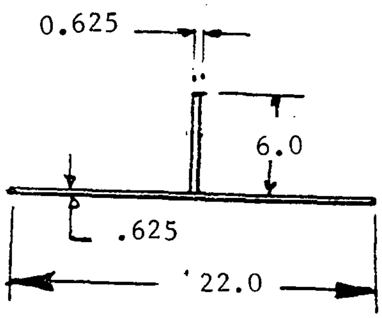
$$Iy = 17.6918 \text{ IN}^4$$

	A	X	AX	AX^2	I_{oy}
Skin Flg	7.021 2.812	0.3125 2.875	2.1940 8.0859	0.6856 23.2470	0.2286 4.7460
-	9.833	-	10.2799	23.9326	4.9746

$$t_{smear} = \frac{9.833}{11.86} = 0.829 \text{ in}$$

$$B_{\phi} = \frac{(29\times10^6)(.829)}{1-.32^2} = 26.7836 \times 10^6 \text{ lb/in}$$

CIRCUMFERENTIAL STIFFNESS AT 68 IN DIA:



$$X = \frac{17.7685}{16.1034} = 1.1034 \text{ in}$$

$$I_y = 11.6848 + 50.5819 - 1.1034\,(17.7685) \text{ in}^4$$

$$I_y = 42.6609 \text{ in}^4$$

	A	x	AX	AX^2	Ioy
Skin	13.3594	.3125	4.1748	1.3046	.4348
Flg	3.7500	3.625	13.5937	49.2773	11.2500
	16.1094		17.7685	50.5819	11.6848

$$t_{smear} = \frac{16.1094}{22.0} = 0.732 \text{ IN}$$

$$B_\theta = \frac{(29\times10^6)(.732)}{(1-.32^2)} = 23.6497\times10^6 \text{ LB/IN}$$

Evaluate membrane loads and stresses at 34-inch radius due to 14,220 lbs concentrated load:

$$\text{Sin}\ \phi = \frac{34}{420} = 0.080952$$

$$N_\phi = \frac{14,220}{2(420)(\pi)(0.080952)^2} = 822 \text{ LB/IN}$$

$$N_\theta = \frac{14,220}{2(420)(0.080952)^2} = 2,583 \text{ LB/IN}$$

$$\epsilon_\phi = \frac{(822-\ .32\ (2583))}{(26.7836\text{x}10^6)(1-.32^2)} = -\ 1.8967\text{x}10^{-7} \text{ IN/IN}$$

$$\epsilon_\theta = \frac{(2583-.32(822))}{(23.6497\text{x}10^6)(1-.32^2)} = 10.9288\text{x}10^{-5} \text{ IN/IN}$$

$$\sigma_\phi = \frac{(29\text{x}10^6)(-1.8967\text{x}10^{-7} + .32\ (10.9288\text{x}10^{-5}))}{(1-.32^2)} \text{ LB/IN}^2$$

$$\sigma_\phi = 1,124 \text{ LB/IN}^2$$

$$\sigma_\theta = \frac{(29\text{x}10^6)\ (10.9288\text{x}10^{-5} + .32\ (-1.8967\text{x}10^{-7}))}{(1-.32^2)} \text{ LB/IN}^2$$

$$\sigma_\theta = 3,529 \text{ LB/IN}^2$$

Combined stresses @ 34-inch radius:

$$\sigma_\phi' = -4,162\ -1,124 = -5,286 \text{ LB/IN}^2$$

$$\sigma_\theta' = -4,690\ -3,529 = -8,219 \text{ LB/IN}^2$$

The stress intensity at this location is:

$$S = -8,219 - (-5,286) = -2,933 \text{ LB/IN}^2$$

Since this is less than 16,700 PSI, ASME code, Para. AD 140 is satisfied.

The margin of safety in the circumferential direction with

$$\sigma_{\theta cr} = 27,000 \text{ PSI is}$$

$$MS_\theta = \frac{27,000}{(1.5)(8219)} -1$$

$$\underline{MS_\theta = +\ 1.19}$$ circumferential @ 34-inch radius

With the four guy wire configuration (spacing at 90^o), and using the total design load of 14,220 pounds, calculate the resulting stresses and margin of safety at 46 inch radius:

$$N\phi = \frac{14,220}{2(420)\ \pi\ (.109523)^2} = 456\ \text{LB/IN}$$

$$N\theta = \frac{14,420}{2(420)\ (.109523)^2} = 1,431\ \text{LB/IN}$$

$$\epsilon\phi = \frac{(456 - .32\ (1431))}{25.4836\times10^6\ (1-.32^2)} = -8.39378\times10^{-8}\ \text{IN/IN}$$

$$\epsilon\theta = \frac{(1,431 - .32\ (456))}{(20.193\times10^6)\ (1-.32^2)} = 7.0900\times10^{-5}\ \text{IN/IN}$$

$$\sigma\phi = \frac{(29\times10^6)(-8.39378\times10^{-8} + .32\ (7.0900\times10^{-5}))}{(1-.32^2)}\ \text{LB/IN}^2$$

$$\sigma\phi = 730\ \text{LB/IN}^2$$

$$\sigma\theta = \frac{29\times10^6(7.0900\times10^{-5} + .32\ (-8.39378\times10^{-8}))}{(1-.32^2)}\ \text{LB/IN}^2$$

$$\sigma\theta = 2,290\ \text{LB/IN}^2$$

The combined stresses from pressure and concentrated loading are

$$\sigma\phi' = -4,162 + (-730) = -4,892\ \text{LB/IN}^2$$

$$\sigma\theta' = -4,690 + (-2290) = -6,980\ \text{LB/IN}^2$$

This stress combination satisfies ASME code PAD-140 and the stress intensity allowable of 16,700 PSI.

The margin of safety in the circumferential direction for skin buckling is

$$MS\ \theta = \frac{11,400}{1.5\ (6980)} - 1$$

$$\boxed{MS\ \theta = +\ 0.088}$$

circumferential skin buckling at 46.0 inch radius.

7. <u>Wind/Blast Over Load for System 2</u>

The following assumptions are made for this analysis:

- Assume 2.0 psig over pressure
- Assume 125 MPH max. wind
- Use 1.5 factor for Vortex shedding and peak gust
- Total cold box weight = 22,000 pounds
- Overall System Dimensions as shown in Figure G-4

Compute drag force using:

$$Fd = 1/2\ C_D \rho A_f V^2; \quad V = 183.33\ \text{Ft/SEC}$$

$$CD = 0.8 \qquad \rho = 0.00238\ \frac{\text{LB-SEC}^2}{\text{FT}^4}$$

$$A_f = \frac{96 \times 174}{144} = 116.0\ \text{FT}^2$$

$$Fd = \frac{0.8}{2}(.00238)(116.0)(183.33)^2$$

$$Fd = 3{,}712\ \text{LBS}$$

With 1.5 Vortex/Gust factor

$$Fd = 5{,}568.\ \text{LBS}$$

Equivalent normal pressure in frontal area is:

$$\text{Press} = \frac{5{,}568}{96 \times 174}\ \frac{\text{LB}}{\text{IN}^2} = .33\ \text{LB/IN}^2$$

6) <u>Wind/Blast over Pressure for System 2</u>

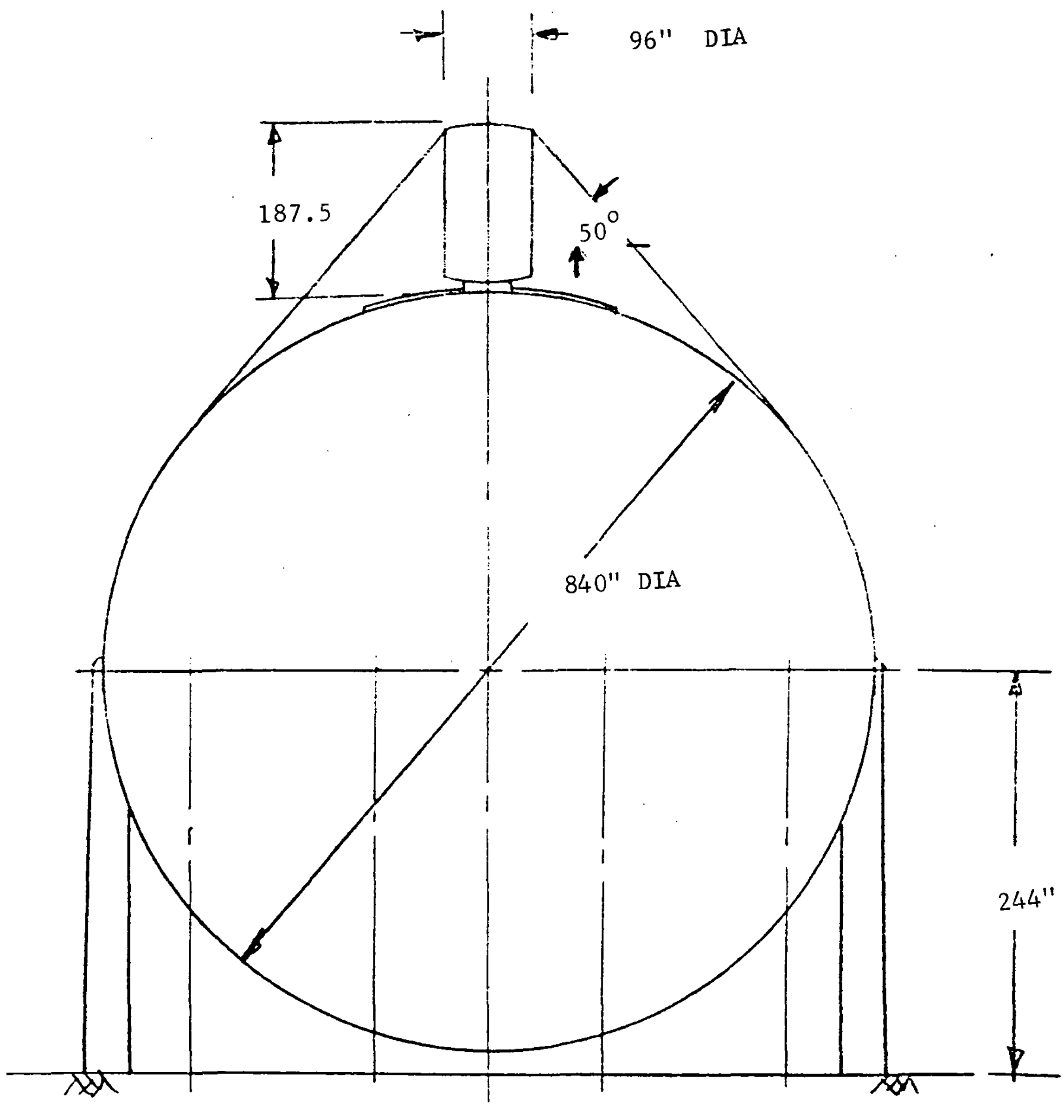


Figure G-4. Overall System Dimensions, System 2

Using Martin Marietta Corporation method:

$$Fd = 0.00256\ Cd\ V^2 \left(\frac{H}{30}\right)^{2/7} A$$

$Cd = 0.8 \qquad V = 125$ MPH @ 30 Ft Elev.

$H = 80.38$ Ft

$$Fd = 0.00256\ (.8)(125)^2 \left(\frac{80.38}{30}\right)^{2/7} (116) \text{ LBS}$$

$Fd = 4919$ LBS

Using 1.5 Vortex/Gust factor

$Fd = 7380$ LBS

Equivalent normal pressure on frontal area

$$\text{Press} = \frac{7380 \text{ LB}}{96 \times 174 \text{ IN}^2} = .44 \text{ LB/IN}^2$$

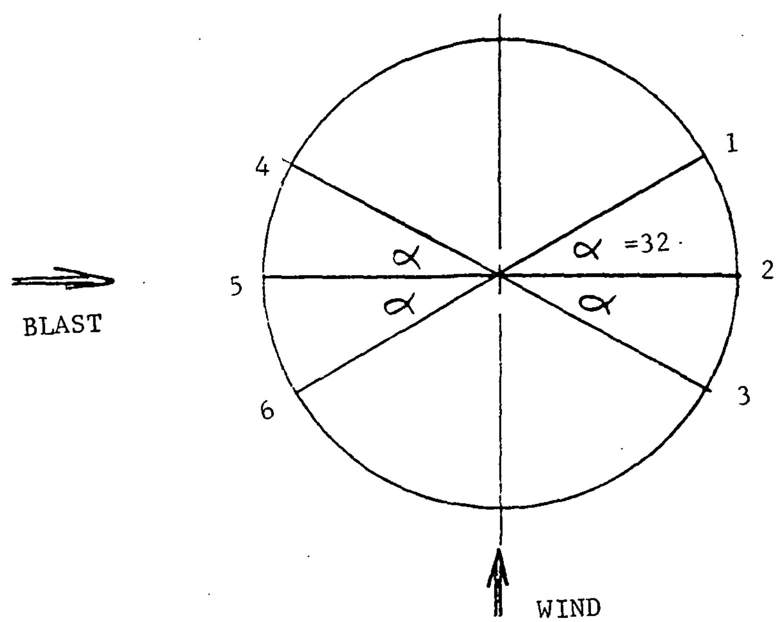
For blast pressure use:

$$\text{Press} = 2.0 \left(\frac{.73}{1.30}\right) = 1.12 \text{ PSI}$$

With reduction due to flat plate/cylinder correction.

To minimize guy wire pre-tension loading, arrange to react blast and wind loading by varying angle (x), as shown, as well as making tangent to shell surface.

(approximately 50°)



Guy Wire Orientation with Respect to Direction of Blast Over Pressure, System 2

Cable tension from wind

$$7,380\ (100.5) = 2\ P_t'\ \mathrm{Cos}\ 50^{\circ}(\mathrm{Cos}(90-\alpha))(172.5+48\ \tan 50)$$

$$P_t' = \frac{7,380\,(100.5)}{2(\mathrm{Cos}50)\mathrm{Cos}(90-\alpha)(229.7)}\ \mathrm{LBS}$$

$$P_t' = \frac{2512}{\mathrm{Cos}\ (90-\alpha)}\ \mathrm{LBS}$$

Cable tension from blast pressure:

$$2\left(\frac{.73}{1.30}\right) (96 \times 174)(100.5) = P_T'' (1 + 2 \cos\alpha) \cos 50 (172.5 + 48 \tan 50)$$

$$P_T'' = \frac{(18,760)(100.5)}{(1+2\cos\alpha)(\cos 50)(229.7)} \text{ lbs}$$

$$P_T'' = \frac{12,770}{(1+2\cos\alpha)} \text{ lbs}$$

Trail and error solution for the equations yields $\alpha =$ 32 degrees, for which:

$$P_T' = 4,740 \text{ lbs}$$

The resulting design load on the sphere is then:

Dead Weight	22,000 pounds
Pre-Tensioned Calble (6 @ 4,740 sin 50)	21,800 pounds

Design Load: $\boxed{43,800 \text{ Pounds}}$

Selection of cable diameter is based on breaking strength, 1.5 factor of safety and 55% elastic limit:

$$\text{Breaking Strength Required} = \frac{4,740 \times 1.5}{.55} = 12,900 \text{ lbs}$$

A 3/8 inch diameter (7x7) or (7x19) stainless steel chord with a breaking strength of 12,000 pounds is recommended. The cables should be pre-stretched 10 cycles at 6000 lbs and then installed with a preload of 4740 lbs.

8. <u>Dewar Stress Analysis for System 2</u>

Calculate membrane loads and stresses in double thickness at 68 inch diameter from 43,800 pounds:

$$\text{Sin } \phi = \frac{34}{420} = 0.08095 \qquad (\phi = 4.64 \text{ degrees})$$

$$N_\phi = \frac{43{,}800}{2\ \pi\ 420(0.08095)^2} = 2{,}530 \ \text{lb/in}$$

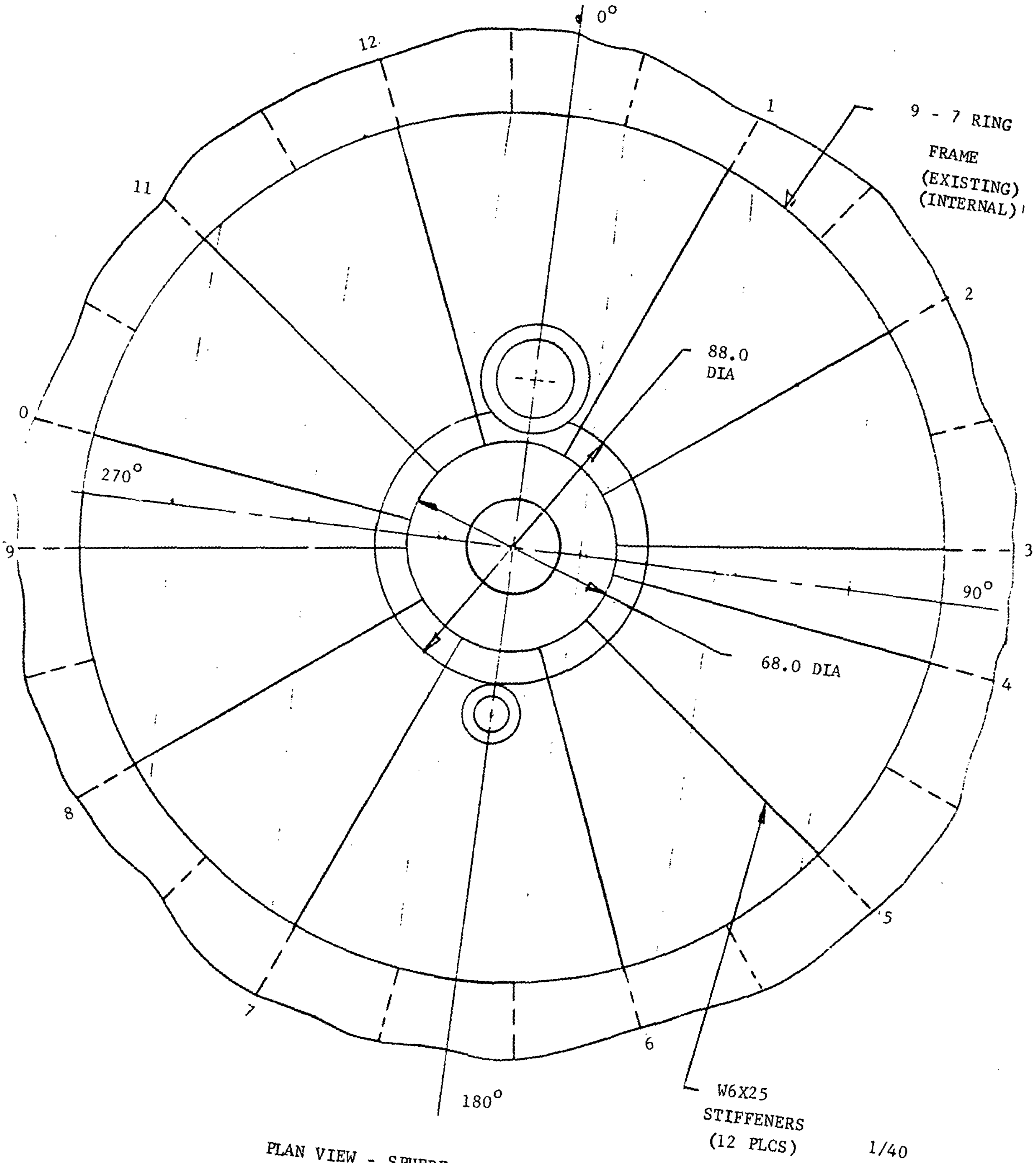
$$N_\theta = \frac{43{,}800}{2(420)(0.08095)^2} = 7{,}960 \ \text{lb/in}$$

Neglecting effect of internal stiffness and using 1/16 inch corrosion allowance on outside plate

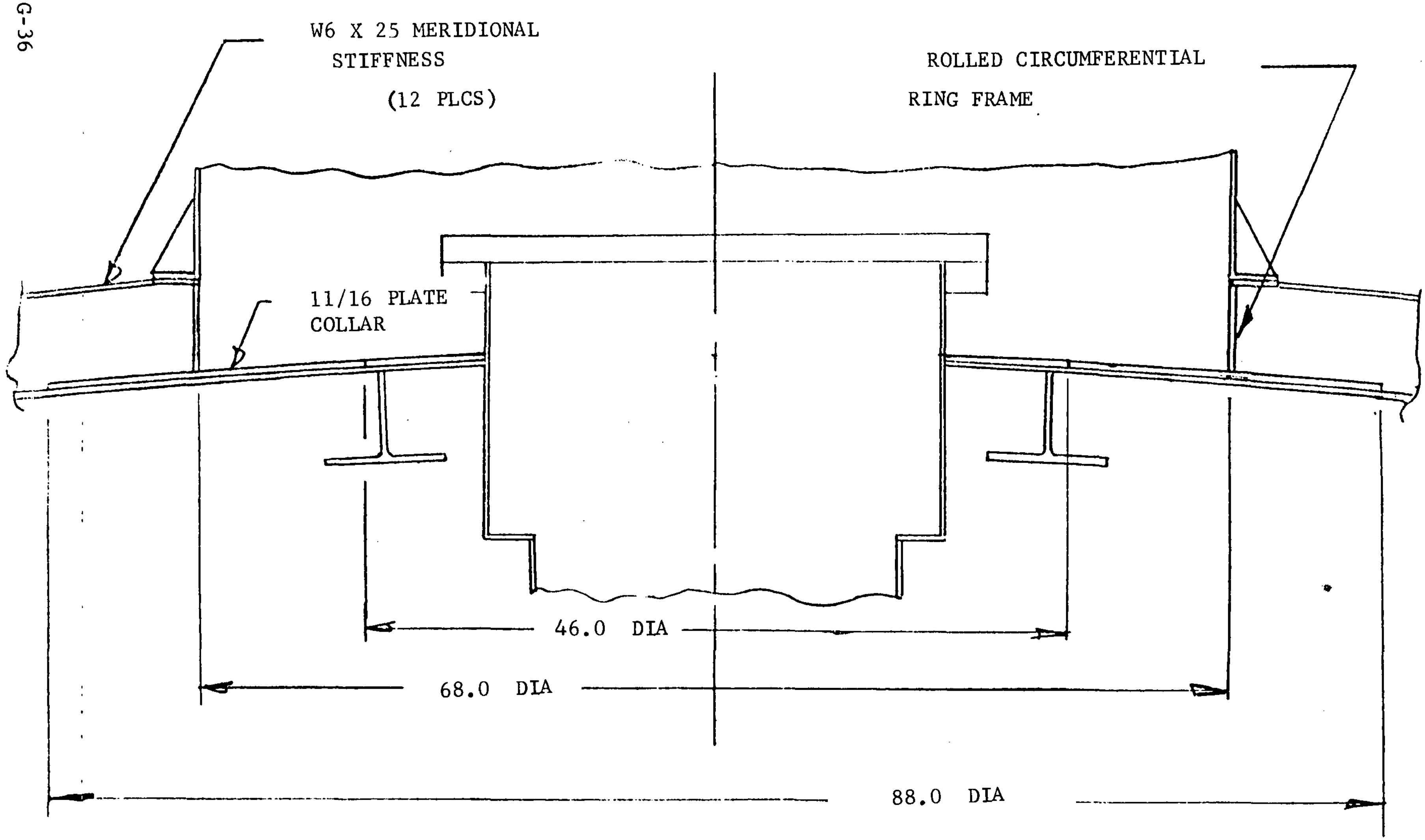
$$t_{eff} = 2(0.6875) - .0625 = 1.3125 \text{ inch}$$

$$\sigma_\phi = \frac{2{,}530}{1.3125} = 1{,}930 \ \text{lb/in}^2$$

$$\sigma_\theta = \frac{7{,}960}{1.3125} = 6{,}065 \ \text{lb/in}^2$$



PLAN VIEW - SPHERE TOP WITH STIFFNESS, SYSTEM 2



SIDE VIEW OF STIFFNESS - SYSTEM 2

When combined with the shell membrane stresses from pressure

$$\sigma_{\phi}' = -4{,}162 - 1{,}930 = -6{,}092 \text{ lb/in}^2$$

$$\sigma_{\theta}' = -4{,}690 - 6065 = -10{,}755 \text{ lb/in}^2$$

This combination of stresses satisfy the ASME code Para. AD-140 Stress intensity allowable of 16,700 lb/in^2 since:

$$S = -10{,}755 - (-6{,}092) = -4{,}663 \text{ lb/in}^2$$

The margin of safety on local crippling using $\sigma_{\theta cr}$ = 27,000 lb/in^2:

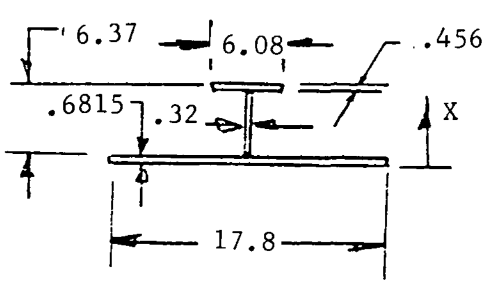
$$MS_{\theta} = \frac{27{,}000}{1.5(10{,}755)} - 1$$

$\boxed{MS_{\theta} = +.67}$ (circumferential at 68-inch dia)

Calculate section properties at 68-inch diameter (neglect collars):

<u>Meridional</u> ($\bar{\alpha}_{AVG}$ = 30 degree spacing)

$$\ell_{CIR} = \frac{68\ \pi\ 30}{360} = 17.80 \text{ in}$$



$$\bar{x} = \frac{30.03863}{16.9025} = 1.7772 \text{ in}$$

$$I_{yy} = \begin{array}{l}6.0459 + 155.89807- \\ (30.03863)(1.7772)\end{array} \text{ in}^4$$

$$I_{yy} = 108.56 \text{ in}^4$$

EL	A	X	AX	AX^2	I_{oy}
Skin	12.2375	0.34375	4.20664	1.44603	0.48201
Web	1.8925	3.6445	6.89721	25.13690	5.51585
FLG	2.7725	6.8295	18.93478	129.31514	.04804
-	16.9025	-	30.03863	155.89807	6.0459

$$B_\phi = \frac{EA_\phi}{1-u^2} = \frac{(29 \times 10^6)\left(\frac{16.9025}{17.80}\right)}{1-.32^2} = 30.679 \times 10^6 \text{ lb/in}$$

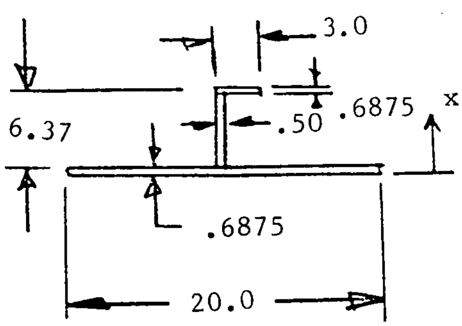
$$D_\phi = \frac{EI_\phi}{1-u^2} \quad \frac{(29 \times 10^6)\left(\frac{108.56}{17.8}\right)}{1-.32^2} = 197.045 \times 10^6 \text{ lb-in}$$

<u>For Stability Calculations</u> - <u>Equivalent Values</u>

$$t_e = \sqrt{\frac{12D_\phi}{B_\phi}} = \sqrt{\frac{(12)(197.045)}{30.679}} = 8.779 \text{ inch}$$

$$E_e = \frac{B_\phi(1-u^2)}{t_e} = \frac{(30.679 \times 10^6)(1-.32^2)}{8.779} = 3.1367 \times 10^6 \text{ lb/in}^2$$

<u>CIRCUMFERENTIAL</u> (@ 68-inch Diameter):



$$\bar{X} = \frac{28.59954}{18.6537} = 1.533$$

$$I_{yy} = 8.26833+129.96455 - (1.533)(28.59454) \text{ in}^4$$

$$I_{yy} = 94.3947 \text{ in}^4$$

EL	A	X	AX	AX^2	I_{oy}
Skin	13.7500	0.34375	4.72656	1.62475	0.54158
Web	3.8412	3.52875	10.02588	35.3788	7.64552
FLG	2.0625	6.71375	13.84710	92.9660	0.08123
-	18.6537	-	28.59954	129.96955	8.26833

$$B_\theta = \frac{EA_\theta}{1-u^2} \quad \frac{(29 \times 10^6)\left(\frac{18.6537}{20.0}\right)}{1-.32^2} = 30.133 \times 10^6 \text{ lb/in}$$

$$D_\theta = \frac{EI_\theta}{1-u^2} = \frac{(29 \times 10^6)\left(\frac{94.3947}{20.0}\right)}{(1-.32^2)} = 152.487 \times 10^6 \text{ lb-in}$$

$$t_e = \sqrt{\frac{12D_\theta}{B_\theta}} = \sqrt{\frac{12(152.487)}{30.133}} = 7.792 \text{ in}$$

$$E_e = \frac{B_\theta(1-u^2)}{t_e} = \frac{(30.133)(10^6)(1-.32^2)}{7.792}$$

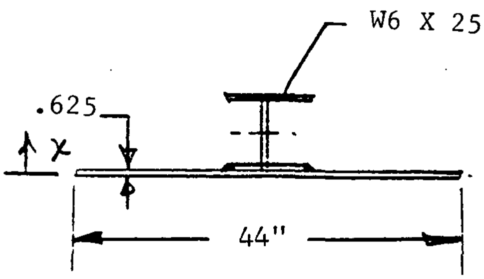
$$E_e = 3.471 \times 10^6 \text{ lb/in}^2$$

At mid-span toward 9-7 frame use 87.0-inch radius and calculate section properties:

$$\theta = 30^{o} \text{ avg. } \ell_c = \frac{30}{360} (2 \times 87 \times \pi) = 45.55 \text{ inch.}$$

Assume skin fully effective with 44-inch spacing:

$$\left.\begin{array}{l} \sigma_{\phi CR} = 21{,}600 \text{ psi} \\ \sigma_{\phi CR} = 11{,}400 \text{ psi} \end{array}\right\} \text{From 2 Unit Analysis}$$



$$\bar{X} = \frac{36.59725}{34.850} = 1{,}050 \text{ in.}$$

$$I_{yy} = 54.192 + 109.3788 - 1.05 (36.59725)$$

$$I_{yy} = 125.146 \text{ in}^4$$

	A	X	AX	AX^2	I_{oy}
Skin W6x25	27,500 7.350	.3125 3.810	8.59375 28.0035	2.6855 106.6933	.895 53.300
-	34.850	-	36.59725	109.3788	54.195

$B_{\phi} = 25.589 \times 10^6$ lb/in $\qquad D_{\phi} = 91.892 \times 10^6$ lb-in

$t_e = 6.56$ in $\qquad E_e = 3.501 \times 10^6$ lb/in^2

By using less effective skin, B_{ϕ} and D_{ϕ} would have larger values and so would t_e and E_e.

For this analysis use:

$t_e = 8.779$ inch and $E_e = 3.1367 \times 10^6$ lb/in^2.

The critical buckling pressure on an equivalent section is (97.5% prob):

$$P_a = \frac{0.1977 E t^2}{R^2 (\sin \alpha)^{1/3}} \qquad \alpha = 19.5^{o}$$

$$P_a = \frac{(0.1977)(3.1367 \times 10^6)(8.779)^2}{420^2 (\sin 19.5)^{1/3}} \text{ lb/in}^2$$

$P_a = 390.6$ psi

To solve for critical buckling pressure on shell structure calculate membrane loads and then apply to shell:

$$N_\phi = N_\theta = \frac{P_a R}{2} = \frac{(390.6)(420)}{2} \text{ lb/in}$$

$$N_\phi = N_\theta = 82{,}020 \text{ lb/in}$$

Strains in shell:

$$\epsilon_\phi = \frac{82{,}020\ (1-.32)}{30.679 \times 10^6 (1 - .32^2)} = 2.0253 \times 10^{-3} \text{ in/in}$$

$$\epsilon_\phi = \frac{82{,}020\ (1-.32)}{(20.193 \times 10^6)(1-.32^2)} = 3.0771 \times 10^{-3} \text{ in/in}$$

The resulting stress levels in the shell are then:

$$\sigma_\phi = \frac{E}{1 - \mu^2} (\epsilon_\phi + \epsilon_\theta)$$

$$\sigma_\phi = \frac{(3.1376 \times 10^6)(2.0253 + .32(3.0771)) \times 10^{-3}}{1 - .32^2}$$

$$\sigma_\phi = 10{,}521 \text{ lb/in}^2$$

$$\sigma_\theta = \frac{E}{1 - \mu^2} (\epsilon_\theta + \mu\epsilon_\phi)$$

$$\sigma'_\theta = \frac{(3.1376 \times 10^6)(3.0771 + .32(2.0253)) \times 10^{-3}}{1 - .32^2}$$

$$\sigma_\theta = 13{,}021 \text{ lb/in}^2.$$

Finally, calculate the critical buckling pressure:

$$\sigma_\theta = \frac{E}{1 - \mu^2} (\epsilon_\theta + \epsilon_\phi) = 13{,}021 \text{ lb/in}^2$$

$$\epsilon_\phi = \frac{P_a R}{2B_\phi} \frac{(1 - \mu)}{(1 - \mu^2)} = \frac{P_a (420)(1 - .32)}{2(30.679 \times 10^6)(1 - .32^2)} \text{ in/in}$$

$$\epsilon_\phi = P_a\,(5.18566 \times 10^{-6}) \text{ in/in}$$

$$\epsilon_\theta = \frac{P_a R\,(1-\mu)}{2B_0\,(1-\mu^2)} = \frac{P_a(420)(1-.32)}{2(20.193 \times 10^6)(1-.32^2)} \text{ in/in}$$

$$\epsilon_\theta = P_a\,(7.8785 \times 10^{-6}) \text{ in/in}$$

Substitution gives:

$$13{,}021 = \frac{29 \times 10^6}{1-.32^2}\,PCR\,(7.8785 + .32(5.18566)) \times 10^{-6}$$

$$P_a = \frac{13{,}021\,(1-.32^2)}{(29)\,(9.5379)} \text{ lb/in}^2$$

$$P_a = 42.25 \text{ lb/in}^2 \quad (\text{with } \sigma_\theta = 13{,}021 \text{ psi})$$

But, $\sigma_{\theta CR}$ = 11,400 psi as determined previously, so P_{cr} must be reduced:

$$\therefore P_a = \frac{11{,}400\,(1-.32^2)}{(29)(9.5379)} \text{ lb/in}^2$$

$$P_a = 37.0 \text{ lb/in}^2 \quad (\sigma_{\theta CR} = 11{,}400 \text{ psi, 97.5\% probability, 95\% confidence})$$

As determined in the System 1 analysis, the critical concentrated load at apex will be that load that results in local instability (shell buckling) from resulting circumferential stresses. With the internal stiffener spacing of 44.0 inches, $\sigma_{\theta CR}$ = 11,400 lb/in^2. With a 30 degree external stiffener spacing at 44 inch radius (edge of additional 11/16" collar), the spacing distance is:

$$\ell_{CIR} = \frac{30}{360}\,2(44)\pi = 23.0 \text{ inches.}$$

Using Bruhn, Pg.C5.3-5.5 and Figure C5.7 Pg. C5.4:

$$\frac{K_C \pi^2 E\, t^2}{12(1-\mu^2)\,\sigma_{0.7} b^2} \quad \text{and } \sigma_{0.7} = 27{,}000 \text{ psi for this material.}$$

with:

$$\frac{a}{b} = 1,\ a = 23 \text{ in.},\ b = 23 \text{ in}$$

$$\frac{(4)\pi^2\ 29 \times 10^6(.625)^2}{12(1-.32^2)(23)^2(27{,}000)} = 2.90$$

$$\sigma_{\theta CR} = \sigma_{0.7} = 27{,}000\ \text{lb/in}^2$$

Using $\sigma_{\theta CR} = 27{,}000\ \text{lb/in}^2$, calculate the concentrated load on shell that would produce this stress level in the basic shell at 44.0-inch radius:

$$\text{SIN}\ \phi = \frac{44}{420}\ 0.10476$$

$$N_\phi = \frac{P_{CR}}{2(420\pi)(.10476)^2} = 0.034528\ P_{CR}\ \text{lb/in}$$

$$N_\theta = \frac{P_{CR}}{2(420)(.10476)^2} = 0.108475\ P_{CR}\ \text{lb/in}$$

$$\epsilon_\phi = \frac{P_{CR}(.034528 - .32(.108475))}{(30.679 \times 10^6)(1-.32^2)} = -6.6818 \times 10^{-12}\ P_{CR}\ \text{in/in}$$

$$\epsilon_\theta = \frac{P_{CR}(0.108475 - .32(0.034528))}{(20.193 \times 10^6)(1-.32^2)} = 5.37516 \times 10^{-9}\ P_{CR}\ \text{in/in}$$

$$\sigma_\theta = \frac{E}{1-\mu^2}(\epsilon_\theta + \epsilon_\phi)$$

$$27{,}000 = \frac{29 \times 10^6(5.37516 \times 10^{-9} + .32(-6.6818 \times 10^{-12}))P_{CR}}{(1-.32^2)}$$

P_{CR} = 155,500 lb (load necessary for circumferential buckling in shell between external stiffeners)

Using straight line interaction formula for combined pressure and concentrated loading at 44 inch radius:

$$\frac{4{,}690(1.5)}{11{,}400} + \frac{43{,}800(1.5)}{155{,}500} = .617 + .423 = 1.040 > 1.00$$

It is desirable for this equation to be less than 1.0, but since this is a preliminary analysis, this combination is considered acceptable.

Check the combined stresses for ASME code, paragraph AD140 requirements:

With P_{cr} = 43,800 pounds at 44 inch radius, the stresses are:

$$\sigma_\phi = -2,424 \text{ lb/in}^2$$

$$\sigma_\theta = -7,605 \text{ lb/in}^2$$

$$\sigma_\phi' = -4,162-2,424 = -6,586 \text{ lb/in}^2$$

$$\sigma_\theta' = -4,690-7,605 = -12,295 \text{ lb/in}^2$$

The stress intensity is then:

$$S = -12,295 - 6,586 = -5,709 \text{ lb/in}^2$$

which is less than 16,700 psi and satisfies the ASME Code paragraph AD140.

The margin of safety for skin crippling in the circumferential direction is:

$$MS_\theta = \frac{27,000}{(1.5)(12,295)} - 1$$

$$\boxed{MS_\theta = +0.46} \text{ (circumferential at 44-inch radius)}$$

Calculate membrane loads and stress levels at external stiffener mid-span radius of 92.0 inches - with 43,800 lb.

$$\text{SIN } \phi = \frac{92.0}{420} = .21905 \qquad \ell_{CIR} = 48 \text{ inches}$$

$$N_\phi = \frac{43,800}{2(420\pi)(.21905)^2} = 346. \text{ lb/in}$$

$$N_\theta = \frac{43,800}{2(420)(.21905)^2} = 1,087. \text{ lb/in}$$

$$\epsilon_\phi = \frac{346 - .32(1,087)}{(30.679 \times 10^6)(1 - .32^2)} = -6.6818 \times 10^{-8} \text{ in/in}$$

$$\epsilon_\theta = \frac{1,087 - .32(346)}{(20.193 \times 10^6)(1 - .32^2)} = 5.3836 \times 10^{-5} \text{ in/in}$$

$$\sigma_{\phi} = \frac{29 \times 10^{6}(-6.6818 \times 10^{-8} + .32(5.3836 \times 10^{-5}))}{1 - .32^{2}} \text{ lb/in}^{2}$$

$$\sigma_{\phi} = 555. \text{ lb/in}^{2}$$

$$\sigma_{\theta} = \frac{29 \times 10^{6}(5.3836 \times 10^{-5} + .32(-6.6818 \times 10^{-8}))}{1 - .32^{2}} \text{ lb/in}_{2}$$

$$\sigma_{\theta} = 1{,}740. \text{ lb/in}_{2}$$

The combined stresses are:

$$\sigma_{\phi}' = -4{,}162 - 555 = -4{,}717 \text{ lb/in}^{2}$$

$$\sigma_{\theta}' = -4{,}690 - 1{,}740 = -6{,}430 \text{ lb/in}^{2}$$

$$S = -6{,}430 - (-4{,}717) = -1{,}713 \text{ lb/in}^{2}$$

This satisfies the ASME Code maximum stress intensity of 16,700 lb/in^2.

For combined loading and straight line interaction in circumferential direction:

$$\frac{4{,}690\,(1.5)}{11{,}400} + \frac{1740(1.5)}{11{,}400} = .617 + .230 = .847 < 1.0$$

This combination satisfies interaction formula.

The margin of safety on shell crippling is ~

$$MS_{\theta} = \frac{11{,}400}{(6430)(1.5)} - 1$$

$$\boxed{MS_{\theta} = 0.188}$$ (Circumferential @ 92-inch radius)

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